POTENTIAL HEALTH AND ENVIRONMENTAL IMPACTS

OF LEAF BLOWERS

SEPTEMBER 15, 1999

CALIFORNIA AIR RESOURCES BOARD

PREPARED FOR THE CALIFORNIA LEGISLATURE

DRAFT FOR COMMENT ONLY

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1.0 EXECUTIVE SUMMARY

The Executive Summary will be prepared for the next draft of this report.

2.0 INTRODUCTION

2.1 Senate Concurrent Resolution 19 - Leaf Blowers

Senate Concurrent Resolution No. 19 (SCR 19) was introduced by Senator John Burton February 23, 1999, and chaptered May 21, 1999. The resolution requests the ARB to prepare and submit a report to the Legislature on or before January 1, 2000, "summarizing the potential health and environmental impacts of leaf blowers and including recommendations for alternatives to the use of leaf blowers and alternative leaf blower technology if the state board determines that alternatives are necessary. . ." and requested that cities and counties refrain from enacting new ordinances to prohibit leaf blower usage until after the ARB has submitted its report. The Legislature, via SCR 19, mentions that there are questions and concerns about potential health and environmental impacts from leaf blowers, and requests that ARB write the report to help to answer these questions and clarify the debate. **The goal of this report, then, is to summarize for the California Legislature existing data on health and environmental impacts of leaf blowers, to identify relevent questions not answered in the literature, and suggest areas for future research.**

The resolution specifies that the report will include a comprehensive review of existing studies of the impacts of leaf blowers on leaf blower operators and on the public at large, and of the availability and actual use of protective equipment for leaf blowers. The receptors identified are humans and the environment; sources of impacts are exhaust, noise, and dust. Because the Legislature specified that ARB use existing information, staff conducted no new studies. In order to locate existing data, staff conducted extensive literature searches, contacted potential resources and experts by telephone and e-mail, and notified the public that we were looking for information via U.S. mail and through a web page devoted to the leaf blower report.

2.2 Health and Environmental Impacts

SCR 19 asks ARB to summarize potential health and environmental impacts of leaf blowers, and thus our first task is to determine what information and analysis would comprise a summary of "health and environmental impacts." The methodology the ARB has used for this report is dependent both on the objectives of SCR 19 and on the available data. As staff discovered, in some areas, such as exhaust emissions, we know much about a hazard; in other areas, such as fugitive dust emissions, we know very little. For both fugitive dust and noise, there are few or no data specifically on leaf blower impacts. For all hazards, there have been no dose-response studies related to emissions from leaf blowers and we do not know how many people are affected by those emissions. Therefore, staff determined to provide the Legislature with a report that has elements of both impact and risk assessments, each of which is described below. The body of the report, then, comprises four components: hazard identification, review of health effects, characterization of the potential impacts of leaf blowers on operators and bystanders, and suggested future research.

Life-cycle Impact Assessment. Life-cycle impact assessment is the examination of potential and actual environmental and human health effects related to the use of resources and environmental releases (Fava et al. 1993). A product's life-cycle is divided into the stages of raw materials acquisition, manufacturing, distribution/transportation, use/maintenance, recycling, and waste management (Fava et al. 1991). In this case, the relevant stage of the life-cycle is use/mainenance. Life-cycle impact assessment tends to focus on relative emission loadings and resources use and does not directly or quantitatively measure or predict potential effects or identify a causal association with any effect. Identification of the significance and uncertainty of data and analyses are important (Barnthouse 1998).

Risk Assessment. A traditional risk assessment, on the other hand, seeks to directly and quantitatively measure or predict causal effects. A risk assessment evaluates the toxic properties of a chemical or other hazard, and the conditions of human exposure, in order to characterize the nature of effects and determine the likelihood of adverse impacts (NRC 1983). The four components of a risk assessment are:

1. *Hazard identification*: Determine the identities and quantities of chemicals present, the types of hazards they may produce, and the conditions under which exposure occurs.
2. *Dose-response assessment*: Describe the quantitative relationship between the amount of exposure to a substance (dose) and the incidence of adverse effects (response).
3. *Exposure assessment:* Identify the nature and size of the population exposed to the substance and the magnitude and duration of their exposure.
4. *Risk characterization*: Integrate the data and analyses of the first three compenents to determine the likelihood that humans (or other species) will experience any of the various adverse effects assocatied with the substance.

The goal of risk assessment is the quantitative characterization of the risk, i.e., the likelihood that a certain number of individuals will die or experience another adverse endpoint, such as injury or disease. A risk assessment is ideally followed up by risk management, which is the process of identifying, evaluating, selecting, and implementing actions to reduce risk to human health and ecosystems (Omenn, et al. 1997). While a risk assessment appears to be preferable because it allows us to assign an absolute value to the adverse impacts, a quantitative assessment is difficult, if not impossible, to perform when data are limited.

2.3 Timeline

SCR 19 requests that ARB deliver this report to the Legislature by January 1, 2000. The ARB's governing board must review and approve the report before its delivery to the Legislature. To allow time for review and comment on the report, it will be released to the Board and the public in early November. Prior to this review, staff conducted two public workshops, on July 28, 1999, to discuss the method by which ARB proposed to conduct the study, and on September 28, 1999, to discuss the first public draft.

ACTIVITY	DATE
Delivery to the Legislature	January 1, 2000
Air Resources Board Public Hearing	December 9, 1999
Public Notice and Report	November 9, 1999
Public Workshop to Review Draft	September 28, 1999
Public Workshop to Discuss Methodology	July 28, 1999
SCR 19 Chaptered	May 21, 1999

2.4 Public Outreach

Staff mailed a letter to about 1,200 people on June 28, 1999, announcing a public workshop, to be held July 29, and requesting all available information on the health and environmental impacts of leaf blowers. Also in June, staff posted a Leaf Blower Report website, with links to the public workshop notice and the text of SCR 19. The website and letter provided the public with a contact address, telephone number, and e-mail address. Twenty-eight people signed in at the workshop.

A second public workshop was announced by letter and on the Leaf Blower Report website on September 2, 1999. The workshop was held September 28, 1999, to provide a forum for discussion of the first public draft of the report. The first draft report was posted on the website and mailed to those who requested it.

In addition to the public workshops, staff met with representatives of the Outdoor Power Equipment Institute (OPEI), the Portable Power Equipment Manufacturers Association (PPEMA), the City of Los Angeles Department of Water and Power, various manufacturers, Citizens for a Quieter Sacramento, and Zero Air Pollution. See Appendix B for a complete list of telephone, in-person, and e-mail contacts.

2.5 History of the Leaf Blower and Local Ordinances

The leaf blower was invented by Japanese engineers in the early 1970s and introduced to the United States as a lawn and garden maintenance tool. Soon after the leaf blower was introduced into the U.S., its use was banned in two California cities, Carmel-by-the-Sea in 1975 and Beverly Hills in 1976, as a noise nuisance (CQS, 1999b). Nevertheless, by 1990, annual sales were over 800,000 nationwide and the number of California cities that had banned use of leaf blowers was up to five. Currently there are twenty California cities that have banned, or in the case of Los Angeles, severly restricted, leaf blowers, and another 80 that have ordinances on the books restricting either usage or noise level or both. Nationwide, two states, Arizona and New Jersey, are considering statewide laws, and five other states have at least one city with a leaf blower ordinance (IME 1999).

The issues usually mentioned by people who object to leaf blowers are health impacts from noise, air pollution, and dust. In addition, some have also argued that the leaf blower is bad for plants because it is usually used to remove dead plant materials that would otherwise contribute to soil health through decomposition (Smaus 1997). Professional gardening firms, however, believe that the leaf blower is an essential, time-saving tool that has enabled them to offer services at a much lower cost than if they had to use rakes, brooms, and water to clean up the landscape (CLCA 1999). Whether or not the use of leaf blowers saves on time and money continues to be debated, with each side making claims for the efficiency or esthetics of leaf blower use versus rakes and brooms. Cities that have not banned leaf blower use have produced studies showing how expensive such a ban would be, while cities that have banned leaf blowers have apparently not seen costs rise significantly (City of Palo Alto 1999, CQS 1999a).

Municipalities usually regulate leaf blowers as public nuisances, in response to citizen complaints (see, e.g., City of Palo Alto 1998a, 1998b, 1999; City of Los Angeles 1999). Two reports were located that address environmental concerns: the Orange County Grand Jury Report (1999), and a series of reports written by the City Manager of Palo Alto (1999, 1998a, 1998b). The City of Palo Alto reports have been produced in order to make recommendations to the City Council on amending their existing ordinance. The Orange County Grand Jury took action to make recommendations that would “improve the quality of life in Orange County,” and recommended that cities, school districts, community college districts, and the County stop using gasoline-powered leaf blowers in their maintenance and clean-up operations. The major findings of each are similar, and are listed in Table 1:

Table 1. Major Findings of the Orange County Grand Jury and City of Palo Alto

Orange County Grand Jury Report (1999)	City of Palo Alto City Manager's Report (1999)
"Toxic exhaust fumes and emissions are created by gas-powered leaf blowers."	"Gasoline-powered leaf blowers produce fuel emissions that add to air pollution."
"The high-velocity air jets used in blowing leaves whip up dust and pollutants. The particulate matter (PM) swept into the air by blowing leaves is composed of dust, fecal matter, pesticides, fungi, chemicals, fertilizers, spores, and street dirt which consists of lead and organic and elemental carbon."	"Leaf blowers (gasoline and electric) blow pollutants including dust, animal droppings, and pesticides into the air adding to pollutant problems"
"Blower engines generage high noise levels. Gasoline-powered leaf blower noise is a danger to the health of the blower operator and an annoyance to the non-consenting citizens in the area of usage."	"Leaf blowers (gasoline and electric) do produce noise levels that are offensive and bothersome to some individuals."

In addition to the findings on exhaust emissions, dust, and noise, the City of Palo Alto made three additional findings:

"Other garden equipment such as gasoline-powered lawn mowers, hedge trimmers, and weed wackers also produce similar noise levels and present many of the same environmental concerns."

“While there are other types of tools that can be used, the majority of them require at least 30 to 50 percent more time to complete the work compared to leaf blowers, and thus significantly increase the costs to the City for clean up of public facilities.”

“Ordinances regulating the use of leaf blowers should be easily enforced and understood in order to be effective and for compliance to occur.”

As will be discussed in more detail later in this report, the findings in these two reports about exhaust emissions and noise are substantiated in the scientific literature. The reports’ findings regarding dust emissions, however, were not documented or based on analysis of actual emissions, but were based on “common sense” knowledge. The City of Palo Alto conducted studies of noise levels from various pieces of equipment, following the ANSI standard when testing leaf blowers, and surveyed their lawn and garden maintenance contractors, asking them to project their costs to the City should they be prohibited from using leaf blowers. The contracts were not competetively bid, however, thus the contractors were free to project rate raises without fear of losing their contracts. The City’s final finding on the stucture of an ideal ordinance was based on surveys of other cities and their experience with enforcing existing ordinances.

2.6 Overview of this Report

The main body of this report comprises five additional chapters, followed by the bibliography and appendices. Chapter 3 decribes the hazards, as identified in SCR 19, from leaf blowers. Exhaust emissions, fugitive dust emissions, and noise are covered in turn, along with who is exposed to each hazard and how society has sought to control exposure to those hazards through laws. Chapter 4 reviews health effects of each of the hazards, with exhaust emissions subdivided into particulate matter, carbon monoxide, and important constituents of unburned fuel. Health effects from fugitive dust are covered in the subsection on particulate matter.

Chapter 5 summarizes the potential health and environmental impacts of leaf blowers, attempting to sythesize the information presented in Chapters 3 and 4. Chapter 6 describes suggested research that, if conducted, would allow researchers to better understand the health and environmental impacts. Finally, Chapter 7 describes engine technologies that could reduce exhaust emissions, including electric power, and discusses methanol fuel and alternatives to leaf blowers.

3.0 DESCRIPTION OF THE HAZARDS

This section of the report describes the three hazards identified by SCR 19 as resulting from leaf blowers. There are undoubtably other hazards that could have been examined, such as whole-body vibration, risk of burning from hot engine parts, or eye damage from blown debris, but the California Legislature chose to limit the scope of this report. Exhaust emissions, noise, and blown dust from leaf blowers have been singled out as the most important issues, as discussed in section 2.5 of this report. Thus, the Legislature requested that ARB examine the three hazards that have been of most concern.

Hazard identification is the first step in an impact or risk assessment. ARB staff have conducted an impact assessment in three steps, the first of which considers the nature of the hazard. In this section, then, each of the three identified hazards are examined in turn, exhaust emissions, blown, or fugutive, dust emissions, and noise. For each, the hazard is described and quantified. For noise, the number of people potentially exposed to the hazard is discussed; for fugitive dust and exhaust emissions the number of people potentially impacted is assumed to be the population of the state. Finally, in this section we also discuss laws that control the particular hazard.

3.1 Exhaust Emissions

3.1.1. Characterization of Technology

Leaf blowers have traditionally been powered by two-stroke gasoline engines, and most still are today.[1] The two-stroke engine has several attributes that are advantageous for

[1]Unless otherwise referenced, this section makes use of material in the ARB's Small Off Road Engine staff report and attachments, identified as MSC 98-02; 1998.

applications such as leaf blowers. Two-stroke engines are lightweight in comparison to the power they generate, and can be used with the engine in any position. Multi-positional operation is made possible by mixing the lubricating oil with the fuel, thus, the engine is properly lubricated even when operated at a steep angle or upside down.

Typical two-stroke designs feed more of the fuel/oil mixture than is necessary into the combustion chamber. Through a process known as “scavenging,” the incoming fuel enters the combustion chamber as the exhaust is leaving. This timing overlap of intake and exhaust port opening can result in as much as 30% of the fuel/oil mixture to be exhausted unburned. Thus, the major pollutants from a two-stroke engine tend to be hydrocarbons, oil-based particulates, and carbon monoxide. A two-stroke engine forms relatively little oxides of nitrogen emissions, because the extra fuel absorbs the heat and keeps peak combustion temperatures low.

Additionally, there are some blowers that utilize four-stroke engines. These blowers are typically "walk-behind" models, used to clean large parking lots and industrial facilities, rather than lawns and driveways. Overall, the engines used in these blowers emit significantly lower emissions than their two-stroke counterparts, with significantly lower levels of hydrocarbons and particulate matter. These four-stroke blower engines have a significantly lower population than the traditional two-stroke blowers and only peripherally fit the definition or commonly-accepted meaning of the term "leaf blower." They are mentioned here only for completeness, but are not otherwise addressed in this report.

3.1.2 Exhaust Emissions Inventory

3.1.2.1 Leaf Blower Population. The best estimates available indicate that there are approximately 410,000 gasoline-powered blowers in use in the state today. This figure has been developed from information gathered through the development and implementation of ARB's small off-road engine regulation. Less than 5,000 of those use four-stroke engines.

Since the small off-road engine regulation does not apply to blowers powered by electric motors, the data regarding the number of electric blowers are not as extensive. However, information shared by the handheld power equipment industry indicates that approximately 60 percent of blowers sold are electric. This would indicate that there are approximately 600,000 electric blowers in California. Most of those would be dependent on the use of a power cord. It must be stressed that the majority of the blower population being electric does not imply that the majority of usage is due to electric blowers. In fact, electric blowers are more likely to be used by homeowners for occasional use, whereas virtually all commercial use involves engine-powered blowers.

3.1.2.2 Emission Inventory. California's emission inventory is an estimate of the amount and types of pollutants emitted by all sources of air pollution. The emission inventory method and inputs for small off-road engines, with power ratings of less than 25 horsepower (hp), was approved by the Board in 1998 (Table 2). Exhaust emissions from leaf blowers contribute from one to nine percent of the small-off road emissions, depending on the type of pollutant, based on the 2000 emissions data. Exhaust emission standards for small off-road engines, which will be implemented beginning in year 2000, will result in lower emissions in the future. By 2010, for example, reactive organic gas (ROG) emissions are expected to shrink by 40% statewide, while CO declines by 35% and PM10 drops 90%. The reductions reflect the replacement of today's blowers with cleaner blowers meeting the year 2000 standards.

Table 2. Leaf Blower Exhaust Emissions, Statewide Inventory (tons per day)

	Leaf blowers 2000	Leaf blowers 2010	All Lawn & Garden, 2000	All Small Off-Road, 2000
Reactive Organic Gases (ROG)	7	4.2	50.24	80.07
Carbon Monoxide (CO)	15	9.8	434.99	1046.19
Fine Particulate Matter (PM10)	0.2	0.02	1.05	3.17

Although leaf blowers by themselves do not constitute a large portion of the inventory, it should be emphasized that emissions from virtually all sources are being controlled at this time and that portions of the state still fall short of meeting the federal ambient air quality standards. Further emissions controls for these engines are not contemplated at this time, but the possibility does exist. Nothing in this report should be construed as supporting or opposing any future action to further control emissions from small two-stroke engines.

3.1.3 Regulating Exhaust Emissions

3.1.3.1 State Regulations. The California Clean Air Act, codified in the Health and Safety Code Sections 43013 and 43018, was passed in 1988 and grants the ARB authority to regulate off-road mobile source categories, including leaf blowers. The federal Clean Air Act requires states to meet national ambient air quality standards (Appendix C). Because portions of California do not meet some of these standards, the State regularly prepares a State Implementation Plan, which specifies measures that will be adopted into law to meet the national standards. Other feasible measures not specified in the state implementation plan may also be adopted.

In December 1990, the Board approved emission control regulations for new small off-road engines used in leaf blowers and other applications. The regulations took effect in 1995, and include exhaust emission standards, emissions test procedures, and provisions for warranty and production compliance programs. In March of 1998, the ARB amended the standards to be implemented with the 2000 model year. Table 3 illustrates how the standards compare with uncontrolled engines for leaf blower engines between 20 and 50 cubic centimeters (cc) in displacement. The few blowers above 50 cc comply with 1995-1999 standards of 120 + 4.0 g/bhp-hr HC+NOx and 300 g/bhp-hr CO. Note that there was no particulate matter standard for 1995-1999 model year leaf blowers, but that a standard will be imposed beginning with the 2000 model year.

Among other features of the small off-road engine regulations is a requirement that production engines must be tested to ensure compliance. Examination of the certification data confirms that manufacturers have been complying with the emissions regulations; in fact, engines that have been identified as being used in blowers tend to emit hydrocarbons at levels that are 10 to 40 percent below the existing limits. This performance is consistent with engines used in string trimmers, edgers, and other handheld-type equipment, which are, in many cases, the same engine models used in leaf blowers.

Table 3
Exhaust Emissions for Leaf Blower Engines
(grams per brake-horsepower-hour)

	Uncontrolled Emissions	1995-1999 Standards	2000 and later Standards
HC+NOx	283 + 1.0	180 + 4.0	54[2]
CO	908	600	400
PM	3.6	---[3]	1.5

3.1.3.2 Federal Regulations. Although the federal regulations for mobile sources have traditionally followed the ARB's efforts, the U.S. EPA has been able to take advantage of some developments following the ARB's March 1998 Board hearing. Specifically, a vocal opponent of the ARB's standards reversed its position upon discovering another means of compliance, specifically two-stroke engines equipped with compression wave technology. Bolstered by this information, the U.S. EPA (1999b) has proposed standards for blowers and other similar equipment that would be more stringent than the ARB standards. ARB plans a general review of off-road engine technology by 2001, and will consider the implications of this new technology in more detail then. A short description is included in "Future Technology" (Chapter 7).

3.1.3.3 South Coast Air Quality Management District Emissions Credit Program. The South Coast Air Quality Management District (SCAQMD), an extreme non-attainment area for ozone, has promulgated Rule 1623 - Credits for Clean Lawn and Garden

[2]For yr 2000, the HC + NOx standards have been combined.

[3]There was no particulate standard for this time period.

Equipment. Rule 1623 provides mobile source emission reduction credits for those who voluntarily replace old high-polluting lawn and garden equipment with new low- or zero-emission equipment or who sell new low- or zero-emission equipment without replacement. The intent of the rule is to accelerate the retirement of old high-polluting equipment and increase the use of new low- or zero-emission equipment. In 1990, volatile organic carbon emissions from lawn and garden equipment in the South Coast Air Basin were 22 tons per day (SCAQMD 1996). To date, no entity has applied for or received credits under Rule 1623 (V. Yardemian, pers. com.)

3.1.4 Summary

Exhaust emissions from leaf blowers consist of the following specific pollutants of concern: reactive organic gases (ROG) from both burned and unburned fuel, and which combines with other gases in the atmosphere to form ozone; carbon monoxide; fine particulate matter; and other toxic chemicals in the unburned fuel. Exhaust emissions from these engines, however, have been controlled since 1995 and will continue to be controlled in the future, with more stringent standards taking effect in 2000. Manufacturers have developed several different methods to comply with the standards. The exhaust emissions from leaf blowers are consistent with the exhaust emissions of other, similar equipment, such as string trimmers. Manufacturers of leaf blower engines have done an acceptable job certifying and producing engines that are below the limits set by the Air Resources Board.

3.2 FUGITIVE DUST EMISSIONS

3.2.1. Definition of Fugitive Dust Emissions

“Blown dust” is the second of the hazards from leaf blowers specifically mentioned in SCR 19. For the purposes of this report, we will use the term “fugitive dust,” which is more in line with the terminology used by the ARB. From the Glossary of Air Pollution Terms, available on the ARB’s website,[4] the following definitions are useful:

> *Fugitive Dust*: Dust particles that are introduced into the air through certain activities such as soil cultivation, or vehicles operating on open fields or dirt roadways. A subset of fugitive emissions.
>
> *Fugitive Emissions*: Emissions not caught by a capture system (often due to equipment leaks, evaporative processes, and windblown disturbances).
>
> *Particulate Matter (PM)*: Any material, except uncombined water, that exists in the solid or liquid state in the atmosphere. The size of particulate matter can vary from coarse, wind-blown dust particles to fine particle combustion products.

Fugitive dust is a subset of particulate matter, which is a complex mixture of large to small particles that are directly emitted or formed in the air. Current control efforts focus on PM small enough to be inhaled, generally those particles smaller than 10 micrometers (μm). So-called coarse particles are those larger than 2.5 μm in diameter, and are directly emitted from activities that disturb the soil, including travel on roads, construction, mining, agriculture, and landfill operations, plus windblown dust, pollen, spores, sea salts, and rubber from brake and tire wear. Those with diameters smaller than 2.5 μm are called fine particles. Fine particles remain suspended in the air for long periods and can travel great distances. They are formed mostly from combustion sources, such as vehicles, boilers, furnaces, and fires, with a small dust component.

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[4] http://arbis.arb.ca.gov/html/gloss.htm

Fine particles can be directly emitted as soot or formed in the atmosphere as combustion products react with gases from other sources (Finlayson-Pitts & Pitts 1986).

Fugitive dust emissions from leaf blowers fall into the category of "uninventoried" fugitive dust emissions and hence are not included in the ARB's emissions inventories. Aside from a study conducted for the SCAQMD (Botsford et al. 1996) to determine whether fugitive dust blown by leaf blowers was a "significant" source in the South Coast Air Basin, there has been no research conducted to estimate dust emissions. ARB staff have, in this report, developed a proposed methodology for estimating fugitive dust emissions from leaf blowers. The estimation presented below begins with the assumptions and calculations contained in the study conducted for the SCAQMD by AeroVironment (Botsford et al. 1996). Additional methodologies and data have been reviewed and derived from the U.S. EPA document commonly termed AP-42, and reports by the Midwest Research Institute; University of California, Riverside; and the Desert Research Institute.

3.2.2 Calculating Leaf Blower Emissions

The fundamental premise in the calculations below is that leaf blowers are designed to move relatively large materials such as leaves and other debris, and hence can also be expected to entrain into the air much smaller particles, especially those below 30 μm diameter, which are termed PM30. Subsets of PM30 inlcude PM10, with diameters below 10 μm, and PM2.5, with diameters below 2.5 μm. Particles below 30 μm are not visible to the naked eye. Note that PM10 includes PM2.5 particles, and PM30 includes PM10 and PM2.5 particles.

3.2.2.1 Generation of Fugitive Dust by Leaf Blowers. The goal of a person using a leaf blower is to move material such as leaves and debris; the leaf blower does this by moving relatively large volumes of air, typically between 350-700 cubic feet per minute, at a high wind speed, typically 150 to 280 miles per hour (hurricane wind speed is >117 mph). While the intent may not be to move dust, this air movement also suspends or resuspends the dust on the surface being cleaned, because a typical surface to be cleaned is covered with a "layer" of dust that is spread, probably non-uniformly, along the surface being cleaned. In order to calculate how much fugitive dust is generated by the action of a blower, we assume that this "layer" of dust can be represented by a single average number, the silt loading. This silt loading value, when combined with the amount of ground cleaned per unit time and the PM weight fractions, produces the estimates of fugitive dust emissions from leaf blowers.

It is recognized and acknowledged that this analysis has been constrained by the language of SRC 19, directing ARB staff to only use existing data, to be a first- or second-approximation of reality. However, common experience indicates that a leaf blower will certainly entrain small particles in the air. The question is: what should those silt loading and size-segregated PM weight fractions be? This section presents the best estimate using existing data.

3.2.2.2 Size Segregation of Particulate Matter. PM emissions are subdivided into the following three categories, operator emissions, local emissions, and regional emissions. They are differentiated as follows:

1) Operator emissions. PM30 emissions will be used to estimate "operator" PM emissions; PM30-sized particles have relatively short settling times, on the order of minutes to a couple of hours, maximum (Finlayson-Pitts and Pitts 1986, Gillies et al. 1996, Seinfeld and Pandis 1998). These would be emissions to which the leaf blower operator and passersby would be exposed.

2) Local emissions. PM10 emissions will be used to estimate "local" PM emissions; PM10 emissions may remain suspended for hours to days in the atmosphere (Finlayson-Pitts and Pitts 1986, Gillies et al. 1996, Seinfeld and Pandis 1998). These emissions would be emissions to which persons in the near-downwind-vicinity would be exposed, for example, residents whose lawns are being serviced and their neighbors, persons in commercial buildings whose landscapes are being maintained or serviced, and persons within a few blocks of the source.

3) Regional emissions. PM2.5 emissions may remain suspended for as long as a week or more (Finlayson-Pitts and Pitts 1986, Gillies,et al. 1996, Seinfeld and Pandis 1998), and hence can be considered as contributors to "regional" PM emissions over a county or air basin.

3.2.2.3 Calculation Assumptions. The method presented uses the following assumptions.

1) Methods used for estimating wind blown dust for paved roads can be applied to estimating fugitive dust emissions from leaf blowers. That is, one can use an "AP-42" type (U.S. EPA 1997) of approach that calculates dust emissions based on the "silt loading" of the street surface(s) in question.

2) The typical leaf blower generates sufficient 'wind speed' to cause sidewalk/roadway dust, in particular, particles 30 micrometers or less in aerodynamic diameter, to become airborne. With nozzle air velocities from 120 to 180 mph, wind speed at the ground would range from 90 mph to 24 mph, according to the AeroVironment study (Botsford et al. 1996).

3) Currently available paved roadside/roadway and gutter silt loadings can be used to calculate emissions from leaf blowers. The actual silt loading values used here are drawn from the ARB's Technical Support Division (ARB 1997a).

4) The size fractions for PM30, PM10, and PM2.5 for paved road dust can be used to calculate emissions from leaf blowers. After consulting Dr. Gregory Muleski at the Midwst Research Institute, staff decided to use the ratio of 'k' factor values to estimate the weight fraction of windblown dust for leaf blower usage. The “k” factor is a dimensionless value that represents the percentage of the total dust loading that is of a certain size fraction.

3.2.2.4 Calculation Methodology. The specific emission factor calculation is as follows:

PM_{size} Emissions = sL x Q x f_{size}

where:

PM_{size} Emissions = PM30, or PM10, or PM2.5 emissions

s = silt loading fraction,

L = total dust/material loading

sL = s x L = silt loading for the area in question

Q = amount of ground cleaned per unit time

f_{size}= PM30, or PM10, or PM2.5 fraction of total dust loading content

Fugitive dust emissions will be estimated for commercial and residential usage. Leaf blowers are used both in residential areas, for lawn and garden care, and commercial areas, such as industrial parks and office complexes, and given that these areas are expected to have different total dust/material loadings and silt loadings, estimates for both residential and commercial leaf blower usage have been prepared.

The following silt loading values were selected from published silt loadings that ranged between 0.02 and 557 grams per square meter (ARB1997a, U.S. EPA 1997, Venkatram et al.

1998). The values selected were based on engineering judgement, rather than on an average of roadway silt loadings. A straight arithmetic average would have been dominated by the few values in the hundreds of grams per square meter. Instead, values were selected based on average values selected from the literature and discussions with persons with background in the field of fugitive dust emissions.

Commercial area silt loading, therefore, is assumed to be 2.0 g/m^2; residential area silt loading is assumed to be 0.035 g/m^2. The population and usage data, obtained from the ARB Mobile Source Control Division, Emissions Analysis Branch, indicate that commercial use accounts for 74.5 % and residential use accounts for 25.5% of per-hour usage. PM10 is assumed to be 19 percent of the weight fraction of the silt, and PM2.5 represents 9 % of the silt weight fraction. The amount of ground cleaned per unit time, Q, is assumed to equal 1,600 m^2/hr .

3.2.3 Characterization of Fugitive Dust Emissions.

This section includes results from this present analysis, as well as results from previous estimates prepared by the ARB and others. For reference, this section begins with two previous leaf blower emissions estimates.

3.2.3.1 Previous Emissions Estimates: ARB, 1991. The ARB's Technical Support Division, in a July 9, 1991 response to a request from Richard G. Johnson, Chief of the Air Quality Management Division at the Sacramento Metropolitan Air Quality Management District (SMAQMD), prepared a per-leaf blower emissions estimate, in grams per hour of dust (McGuire 1991). PM10 emissions were reported as being 1,180 g/hr, or 2.6 lb/hr. If this emission factor is combined with current statewide hours-of-operation data of 97,302 hr/day of leaf blower usage, this would produce an emission inventory of 126.5 tpd of PM10.

3.2.3.2 Previous Emissions Estimates: SMAQMD. Sacramento Metropolitan Air Quality Metropolitan District (SMAQMD) staff (Covell 1998) estimated that "Dust Emissions (leaf blowers only)" are 3.2 tpd in Sacramento County. The memo included commercial and residential leaf blower populations (1,750 commercial and 15,750 residential), and hours of use (275 hr/yr for commercial and 10 hr/yr for residential). Using these values one can "back calculate" the assumed g/hr emission factor for "particulate matter". The resulting emission factor is 1,680 g/hr, or 3.7 lb/hr. The resulting statewide emission inventory is 180 tpd.

3.2.3.3 Emission Factors - This Study. Two emission factors have been calculated (Table 4): one for commercial usage, which assumes a higher silt loading of 2.0 g/m^2, and a second one for residential usage, which assumes a low silt loading of 0.035 g/m^2.

Table 4. Estimated Emission Factors, This Study
grams per hour, g/hr (pounds per hours, lb/hr)

Emission Factor	Commercial	Residential
Total Suspended Particulate	3200 (7.04)	56 (0.12)
PM10	608 (1.34)	10.64 (0.02)
PM2.5	288 (0.63)	5.04 (0.01)

3.2.3.4 Statewide Emissions Inventory - This Study. The statewide emissions inventory has been estimated by combining the hours of operation by equipment category (residential and commercial). Residential usage includes fugitive dust emissions contribution from electric leaf blowers, of which there are an estimated 600,000 in California; all electric leaf blowers are assumed to be in residential usage.

Table 5. Statewide Emissions Inventory, This Study
tons per day (tpd)

Emissions Inventory	Commercial	Residential	Total
Total Suspended Particulates	255.5	2.5	258
PM10	48.5	0.5	49.0
PM2.5	23.0	0.2	23.2

3.2.3.5 Comparison of Emission Factors and Inventories. The 1996 statewide estimates for paved road dust, unpaved road dust, and fugitive windblown dust are 400 tpd, 610 tpd, and 310 tpd, respectively. Thus, the total suspended particulate emissions from this study are on a scale with these three sources. The entire 1996 PM10 emission inventory, which does not include leaf blower dust emissions, was 2,400 tpd. The contribution from leaf blower fugitive dust is, therefore, estimated to be about two percent of the statewide PM10 emissions inventory. A finer scale analysis, by air district, would shed light on whether or not dryer areas of the state experience a greater emissions impact than wetter areas. Unfortunately, ARB lacks the data necessary to make a finer scale, air district by air district, analysis for this study. It must be stressed that this estimate is highly dependent on silt loading values, which have not been specifically defined for leaf blower usage, and thus these estimates should be considered to be first-order approximations.

Comparing the estimates derived in this study with the previous ARB estimate (McGuire 1991), we find that the major difference is the weight fraction of total suspended particulates that comprises PM10. The 1991 estimated emission factor for PMtsp was 5.7 lb/hr, or 2585 g/hr, comparable to this study's emission estimate of 7 lb/hr, or 3200 g/hr. In the earlier study, however, ARB assumed that 45% of the PMtsp was PM10, whereas this study assumes 19%.

3.2.4 Chemical Composition

In keeping with the direction to use existing data, the use of ARB's size-segregated chemical speciation profiles for paved road dust was considered to chemically characterize leaf blower PM emissions.However, because of the great uncertainty as to the composition of leaf blower dust, paved road dust chemical characteristics were not used in estimating health impacts, but are presented in Appendix D for information. In addition to soil particles, paved road dust emissions contain contributions from tire and brake wear particles. A Fresno County Air Pollution report noted that street sweepings in Fresno were found to contain arsenic, chromium, lead, mercury and other metals. The ARB's own chemical speciation profiles for paved road dust also show small percentages of these substances.

3.2.5 Regulating Fugitive Dust Emissions

Fugitive dust emissions are generally regulated as a nuisance, although PM10 and PM2.5 are specifically addressed through the state planning process as criteria air pollutants. There are no explicit federal, state, or local regulations governing leaf blower fugitive dust emissions.

3.2.5.1 State and Federal PM10 and PM2.5 Standards. The California and Federal ambient air quality standards for PM10 and PM2.5 are located in Appendix C. Any state that has air basins not in attainment for the standards must submit a plan to U.S. EPA on how they will achieve compliance. For California, most of the state violates the PM10 standard; attainment status has not yet been determined for the new PM2.5 standard (promulgated July 18, 1997). California, and its air districts, is therefore required to control sources of PM10, including fugitive dust.

3.2.5.2 Local District Regulations. Many air districts have a fugitive dust control rule that prohibits activities that generate dust beyond the property line of an operation. For example, the SCAQMD Rule 403 states: “A person shall not cause or allow the emissions of fugitive dust from any active operation, open storage pile, or undisturbed surface area such that the presence of such dust remains visible in the atmosphere beyond the property line of the emission source.” In addition, rules may place limits on the amount of PM10 that can be detected downwind of an operation that generates fugitive dust; for SCAQMD that limit is 50 $\mu g/m^3$ [SCAQMD Rule 403]. The Mojave AQMD limits PM emissions to 100 $\mu g/m^3$ [Mojave AQMD Rule 403]. Others, such as the San Joaquin Unified APCD, define and limit visible emissions (40% opacity) from activities that generate fugitive dust emissions [SJUAPCD Rule 8020]. Finally, another approach is to simply request individuals take “reasonable precautions” to prevent visible particulate matter emissions from moving beyond the property from which the emissions originate [Great Basin Unified APCD Rule 401].

3.2.6 Summary

The data presented indicate that the PM10 emissions impact from fugitive dust suspended by leaf blowers are small, but not insignificant, at about 2 percent of the total PM10 inventory. Previous fugitive dust estimates are in the same neighborhood as the estimates developed and presented here. For example, the ARB's Technical Support Division estimated statewide fugitive dust emissions to be about 5 percent of the statewide PM10 emission inventory in 1991, and the SMAQMD (1998) estimated leaf blower fugitive dust emissions to be about 2 percent of the Sacramento county PM10 air burden.

To what extent leaf blowers are efficient mechanisms for entraining PM30 and smaller particles in ambient air can only be demonstrated empirically, using real leaf blowers to clean selected surfaces that are representative of actual leaf blower usage. A more definitive estimate of leaf blower fugitive dust emissions will require a research project to determine and verify appropriate calculation parameters, determine representative silt loadings, determine actual fugitive dust emissions through source testing, and determine the chemical composition of leaf blower generated fugitive dust.

3.3 NOISE EMISSIONS

3.3.1 Defining Noise

The third of the hazards from leaf blowers identified in SCR 19 is noise. Noise is the general term for any loud, unmusical, disagreeable, or unwanted sound. Noise can damage hearing, interrupt communication, disturb rest and sleep, and cause psychological and physiological changes that may lead to poor health (WHO 1980). The adverse physiological effects of noise include damage to hearing and may include elevated blood pressure and changes in body chemistry leading to irritability and anxiety. Psychological effects range from annoyance to interference with communication, sleep, work performance, and behavior (Kryter 1994). In this report, noise will be used to refer both to unwanted sounds and sounds that damage hearing. The two qualities, although related, do not always occur together.

The effects of sound on the ear are determined by its quality, which consists of the duration, intensity, frequency, and overtone structure, and the psychoacoustic variables of pitch, loudness, and tone quality or timbre, of the sound. Long duration, high intensity sounds are the most damaging and usually perceived as the most annoying. High frequency sounds, up to the limit of hearing, tend to be more annoying and potentially more hazardous than low frequency sounds. Intermittent sounds appear to be less damaging than continuous noise because the ear appears to be able to recover, or heal, during intervening quiet periods. Random, intermittent sounds, however, may be more annoying, although not necessarily hazardous, because of their unpredictability (Suter 1991).

The context of the sound is also important. While certain sounds may be desirable to some people, for example, music at an outdoor party, they may be considered noise by others, for example, those trying to sleep. Even desirable sounds, such as loud music, may cause damage to hearing and would be considered noise in this context. Thus, not only do loudness, pitch, and impulsiveness of sound determine whether the sound is "noise," but also the time of day, duration, control (or lack thereof), and even one's personality determine whether sounds are unwanted or not.

The physical and psychoacoustic characteristics of sound, and thus noise, are described in more detail in Appendix E. The discussion is focused on information necessary for the reader to understand how sound is measured, and clarify measures of leaf blower sound. The interested reader is referred for more information to any physics or acoustic reference book, or the works referred to herein.

3.3.3 Measuring the Loudness of Sound

The weakest intensity of sound a health human ear can detect has an amplitude of 20 millionths of a Pascal[5] (20 μPa). The loudest sound the human ear can tolerate, the threshold of pain, has an amplitude one million times larger, or 200,000,000 μPa. The range of sound intensity between the faintest and the loudest audible sounds is so large that sound pressures are expressed

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[5]Other units used to represent an equivalent sound pressure include 0.0002 μbar, 0.0002 dyne/cm^2, and 20 μN/m^2.

using a logarithmically compressed scale, termed the decibel (dB) scale. The decibel is simply a unit of comparison between two sound pressures. In most cases, the reference sound pressure is the acoustical zero, or the lower limit of hearing. The decibel scale converts sound pressure levels (SPL) to a logarithmic scale, relative to 20 μPa.

$$\text{SPL, dB} = 10 \log_{10} (P^2/P_o^{\,2})$$

Where P is the pressure fluctuation in Pascals,

P_o is the reference pressure; usually 20 μPa.

(Insert figure illustrating the relationship between Pa, dB, and qualitative measures)

Thus, from this relationship, each doubling of sound pressure levels results in an increase of 6 dB. From the relationship, above, between sound intensity and distance, we find also that doubling the distance between the speaker (source) and listener (receiver), drops the level of the sound by approximately 6 dB. Sound pressure levels are not directly additive, however, but must first be expressed as mean square pressures before adding (WHO 1980). The equation is as follows:

$$\text{SPL} = 10 \log_{10} [10^{\text{SPL}_1/10} + 10^{\text{SPL}_2/10} + ... + 10^{\text{SPL}_x/10}]$$

For example, if two sound sources have SPLs of 80 dB and 90 dB, then the resulting sound pressure is 90.4 dB:

$$\text{SPL} = 10 \log_{10} [10^8 + 10^9] = 90.4 \text{ dB}$$

Adding two sounds with the same SPL, for example 90 dB, increases the total SPL by 3 dB, for example to 93 dB.

3.3.3.1 Loudness description. Sound pressure level, however, does not completely describe loudness, which is a subjective perception of sound intensity. Loudness increases with intensity, but is also dependant on frequency. Thus the human ear may not perceive a six dB increase as twice as loud. In general, people are more sensitive to sounds in the middle of the range of hearing, from around 200 Hz to 5000 Hz. Fletcher and Munson (1933) first established the 1000-Hz tone as the standard sound against which other tones would be judged for loudness. Later, Stevens (1955) proposed that the unit of loudness be termed the sone, and that one sone be ascribed to a 1000-Hz tone set at a SPL of 40 dB under specified listening conditions. On the sone scale, a sound twice as loud as one sone would be two sones, four times as loud would be four sones, and so on. Equal loudness contours, identified in units of phons, demonstrate how the SPL, in dB, of a tone must be varied to maintain the perception of constant loudness.

Ideally, sound measurement meters would give a reading equal to loudness in phons, but because phons are based on human perception, and perception process will vary from individual to individual, this is not practical for most purposes. While standards for measurement in phons have been developed, they are only used under specific circumstances when high precision is required (WHO 1980). For practical purposes, loudness is recorded in decibels, and measured by applying a filter that weights sound pressure level measurements as a function of frequency, approximately in accordance with the frequency response characteristics of the human ear. Several weighting systems have been developed, but the one in most common use is the A-weighted filter. The A-filter provides the highest correlation between physical measurements and subjective evaluations of the loudness of noise. EPA's Office of Noise Abatement and Control recommended A-filter weighting to describe environmental noise because it is "convenient to use, accurate for most purposes, and is used extensively throughout the world (EPA 1979)." Levels are commonly expressed as dBA.

3.3.3.2 Sound level measurement. The American National Standards Institute, Inc. (ANSI) has developed a method for measuring the sound levels from leaf blowers. The purpose of the standard method is to establish sound level labeling requirements for leaf blowers applicable to noise received by bystanders. The standard also includes requirements for safety precautions to be included in manuals for use by operators (ANSI 1996). The ANSI standard specifies a test area in a field in which natural ground cover does not exceed three inches in height and which is free of any large reflecting surfaces for a minimum of 100 ft from the blower (see Appendix F). The sound level meter must be set for slow response and the A-weighting network. Once the blower is adjusted and running properly, the receiver (microphone) is set up 50 ft from the operator and 4 ft above ground. Sound level readings are taken in a circle every 45 degrees for a total of eight readings, as either the operator rotates or the microphone is moved. The eight readings are then averaged and reported to the nearest decibel.

Although in wide use, the method has been criticized as sometimes generating unreproducible results. Typical comments expressed in meetings with ARB staff were to the effect that the manufacturer-reported sound levels for leaf blowers are often lower than those obtained by some third party testers. Indeed, Consumer's Union, which tests products and publishes *Consumer Reports*, reported in its April 1997 issue that the *Echo PB46LN*, which *Echo* lists as a quiet 65 dBA, tested at 69.5 dBA, only slighty quieter than most other leaf blowers (Consumer Reports, 1997a). This issue has prompted the industry to reexamine the ANSI standard, and it is in the process of being revised (Dunaway 1999). Other comments about the method criticize the fundamental requirements for testing in an open field, with no reflecting surface for 100 ft, and the receiver 50 ft away, as being unrealistic and unrepresentative of real-world use (Allen 1999).

While the ANSI method yields sound level exposures for a bystander, the noise level exposure for the operator is measured using an audiodosimeter. For occupational exposures, the dosimeter reports the noise dose as a percentage relative to the permissible exposure level of 90 dBA (8 CCR General Industry Safety Orders, Article 105, Appendix A; 29 CFR §1910.25). The eight-hour time-weighted average sound level experienced by the worker is then calculated from the dose, using a formula specified in regulations. Additional specifications can be found in the OSHA and Cal/OSHA Technical Manuals.[6]

3.3.4 Noise in California

3.3.4.1 Noise Sources. The major sources of noise today are likely the same as they were twenty or more years ago when the U.S. EPA reported that the dominant sources for outdoor noise in urban residential settings were motor vehicles, aircraft, and voices (U.S. EPA 1974). In order to the examine the sources of noise impacting the American population, the U.S. EPA contracted for a study of noise and the number of people exposed to noise. The study focused on man-made mechanical noises, excluding other human voices and animals. The results ranked major sources, by number of people exposed, as road traffic, aircraft, construction, railroads, and industrial equipment and activities (U.S. EPA 1981b).

3.3.4.2 Numbers of People Potentially Exposed: the Public. It is not possible to state with any certainty how many people in California are exposed to noise from leaf blowers. Indeed, the most recent nationwide estimate of the number of people exposed to noise from various sources dates from 1981. In that study, the U.S. EPA estimated that 730,000 people were

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[6]OSHA's Technical Manual is available on their website (www.osha.gov) and noise measurement is in Section III, Chapter 5. Cal/OSHA's manual is available from Cal/OSHA directly.

exposed to noise from leaf blowers above the day-night average sound level of 45 dBA (U.S. EPA 1981). The use of leaf blowers has grown since 1980, however, and thus these numbers cannot be scaled for an estimate of the number of Californians exposed to leaf blower noise today.

As California's population has grown almost 41% since 1970 (CDF 1998, CDF 1999), population density, and thus noise exposure, has increased. California classifies counties as being metropolitan or non-metropolitan, based on the Bureau of the Census's categorization of standard metropolitan statistical areas as containing or being close to a large city. As of January 1, 1999, the thirty-four metropolitan counties comprise 96.7% of California's population, or about 32.67 million people. The population of Californians who live in non-metropolitan counties, while small at 3.3% of the total, or 1.11 million people, has increased faster than the population in metropolitan counties (47.1% increase versus 40.5% increase, 1970-1999) and thus even noise exposures in the lowest populated counties have likely increased over the past thirty years.

Unfortunately, without a comprehensive and current survey of noise exposures in California, it is not possible to determine, from available data, how many Californians are exposed to noise, and in particular exposed to noise from leaf blowers. The only conclusion is that the number of people affected by noise is likely increasing as population density increases even in non-metropolitan areas of the state. How many people are exposed to, and annoyed by, noise from leaf blowers is a question for future research.

3.3.4.3 Numbers of People Potentially Exposed: the Operator. One can assume that all gardeners are exposed to the noise from leaf blowers, either as an operator or from working in close proximity to the operator. From the California database of employees covered by unemployment insurance, in the fourth quarter of 1998 there were 59,489 workers reported by

6790 firms, in the SIC Code 0782, Lawn and Garden Services (M. Rippey, pers. comm). This number is assumed to be the lower bound of those exposed, as there are likely many workers employed in the underground economy, who neither report their earnings nor are covered by unemployment insurance. Future research could test the hypothesis that all lawn and garden service workers are exposed, as operators or from working in close proximity, to the noise from leaf blowers.

3.3.5 Regulating Noise

3.3.5.1 Federal Law. The Noise Control Act of 1972 established a statutory mandated national policy "to promote an environment for all Americans free from noise that jeopardizes their public health and welfare." The Office of Noise Abatement and Control was established within the EPA to carry out the mandates of the Noise Control Act. The Office of Noise Abatement and Control published public health and welfare criteria; sponsored an international conference; examined dose-response relationships for noise and its effects; identified safe levels of noise; promulgated noise regulations; funded research; and assisted state and local offices of noise control; until it was defunded in 1981 and 1982 by the Reagan administration (Suter 1991; Shapiro 1991). In its almost ten years of operation, EPA produced several documents that are still relevant, if dated, today.

The hearing of workers is protected by regulations promulgated under the Occupational Safety and Health Act of 1970. As California employers fall under California's equivalent program, hearing protection law will be covered below under state law.

3.3.5.2 State Law. California enacted the Noise Control Act of 1973 to "establish a means for effective coordination of state activities in noise control and to take such action as will be necessary...” [HSC §46000(g)]; the office was established within the California Department of Health Services. One of the primary functions of the office was to provide assistance to local governmental entities that develop and implement noise abatement procedures, and several guidelines were written. The office, however, was defunded by statute beginning in the 1993-1994 fiscal year. Very little remains of the office, and no guidelines were obtained or suggested as relevant for this report.

California’s counterpart to OSHA, the Cal/OSHA, has a General Industry Safety Order [8 CCR Article 105 §5095-5100] for the control of noise exposure that is very similar to the federal OSHA regulations. Employers are required to provide employees with hearing protection when noise exposure exceeds 90 dBA in an eight-hour work day; as noise levels increase, the allowable exposure duration also decreases. The permitted duration for an employee exposed to 103 dBA, for example, is one hour and nineteen minutes in a work day [8 CCR §5096 (a)(b)]. Employers are allowed to use personal protective equipment to reduce sound level exposures if administrative or engineering controls are not feasible or fail to reduce sound levels within permissible levels. When sound level exposure exceeds 85 dBA for an 8-hour time-weighted average, employers are required to provide a hearing conservation program at no cost to employees. The hearing conservation program includes audiometric testing of hearing, provision of hearing protectors, training, and record keeping.

3.3.5.3 Local Ordinances. In contrast to the low level of activity on noise control at the federal and state levels, local California cities and counties have been very active in regulating and enforcing noise standards. About twenty cities have banned the use of gasoline-powered, or gasoline- and electric-powered leaf blowers, from use within their city limits (City of

Palo Alto 1999). If you include the City of Los Angeles, which has a very restrictive ordinance that works like a ban, about 13% of Californians live in cities that ban the use of leaf blowers, and six of the ten largest California cities have ordinances that restrict or ban leaf blowers. All together, about one hundred California cities have ordinances that restrict either leaf blowers specifically or all gardening equipment generally, including the cities with bans on leaf blower use.

The restrictions on leaf blowers fall into four basic categories, with many cities employing a combination of approaches: time of day/day of week, noise levels, specific areas, and educational (City of Palo Alto 1999). Time of day/day of week ordinances are the most common and are used to control when leaf blowers can be operated. Typically, hours of use are restricted to times between 7:00 a.m. and 7:00 p.m., and days of use are either Monday through Friday or Monday through Saturday, and sometimes including Sunday, with shorter hours on the weekend, based on the assumption that leaf blower noise is most offensive during the evening and night time hours, and on the weekend. There may be exceptions for homeowners doing their own yardwork and for work in commercial areas. Time of day/day of week ordinances are relatively easy to enforce. A problem with these ordinances, however, is that they ignore the needs for quiet during the day of babies, young children, and their caretakers; day-sleepers; the ill; the retired; and a growing population of those who telecommute.

Some cities regulate leaf blower use based on noise levels recorded at a specified distance from the operator. Palos Verdes Estates and Davis, for example, set the noise level at 70 dBA at 50 ft, and Newport Beach and San Diego have a 65 dBA at 50 ft restriction. Davis allows single-family homeowners to avoid the restriction if the leaf blower is operated for less than ten minutes.

Palos Verdes Estates requires blowers to be tested and certified by the city. Otherwise, a noise level restriction is very difficult to enforce as it would require the enforcement officers to carry and be trained in the use of sound level meters. These rules target the control of noise from blowers, and, if effectively enforced could protect those who are home during the day and thus are not protected by the time of day/day of week ordinances.

Recognizing that leaf blowers are often perceived as most offensive when used in residential areas, many cities stipulate usage restrictions only in residential areas, or within a certain distance of residential areas. The distance restrictions prohibiting the use of leaf blowers range from 100 ft, in Foster City, to 500 ft, in Los Angeles, from residential areas. This type of ordinance protects those who are at home and in need of quiet during the day, but does not address issues of those who work and recreate in commercial or other non-residential areas.

Cities sometimes couple area restrictions with user guidelines, such as prohibitions on blowing debris onto adjacent properties, and require operators be educated on the proper use of leaf blowers so as to minimize noise levels and environmental issues. These educational approaches are generally not oriented towards enforcement, but seek to change operator behavior. Educational approaches are often endorsed by landscapers and manufacturers, who believe that much of the discord over leaf blower usage originates with the few gardeners who use them incorrectly or inconsiderately. For example, an organization calling itself “LINK” or “Landscapers Involved With Neighborhoods and Kids” promotes educating operators to use their leaf blowers at half-throttle within 150 ft of homes (LINK 1999).

3.3.6 Noise From Leaf Blowers

In a survey of Southern Californian gardeners by a consumer products manufacturer (Anon 1999), the top three ranked attributes of a desirable leaf blower were, in order, powerful, quiet, and light-weight. Important features were identified as “backpack mounted,” “noise below legal limits,” and “variable speed.” When asked what they don’t like about their leaf blowers, the most commonly cited problem was “noise.” Taken together, these answers suggest that loud noise from leaf blowers is not only an issue for the public, but is also a major issue of concern for the gardeners who use them.

Manufacturer-reported noise levels from leaf blowers are summarized in Appendix G; all reported noise levels are assumed to have been measured following the ANSI standard method, with the receiver 50 ft from the blower. The reported levels are based on personal communications with manufacturers, trade association representatives, or statements in promotional literature. Although the manufacturers do not report personal exposure data for the operator, the instruction manuals received with leaf blowers, do suggest that the operator wear hearing protection at all times.

3.3.6.1 Bystander noise exposure. For backpack and hand held blowers, sound levels range from a reported relatively quiet 62 dBA to a very noisy 75 dBA. Bearing in mind the logarithmic decibel scale, the difference in a leaf blower at 62 dBA and one at 75 dBA, a 13 dBA range, represents more than a quadrupling of the sound pressure level, and would be perceived by a listener as two to four times as loud. The rule of thumb is that, while each six dB increase or decrease represents a doubling of sound pressure level, the listener will perceive a ten dB increase as twice as loud (MPCA 1987).

There are presently three gasoline-powered backpack leaf blowers that are reported by their manufacturers to be very quiet: the Echo PB46LN (65 dBA), the Maruyama BL4500SP (62 dBA), and the Toro BP6900 (62 dBA). For backpack leaf blowers, Echo sells slightly under one-third of the total number of backblowers sold. In 1996, the most popular Echo backpack leaf blower, based on sales, was the Echo PB-400E, one of the noisiest at 74 dBA. By 1999, however, the quieter PB46LN had surpassed the PB-400E in sales (Will, L., pers. com.). These data are not surprising, especially as the purchasers are presumably the same professionals who identified noise as one of their biggest issues in the survey discussed above.

The range of reported sound levels for hand held blowers is roughly the same as for back pack blowers, from 63 dBA to 75 dBA. The quietest hand held models are electric-powered: the RedMax “Vroom,” at 63 dBA, and the Stihl BGE 60, also at 63 dBA. Some manufacturers, such as Husqvarna, Stihl, Ryobi, and Toro, did not report the sound levels of most of their models in materials available to the ARB.

Perhaps because the low noise models represent a great leap in noise control, the manufacturer reported levels have been challenged. The Echo PB46 LN was the first quiet leaf blower on the market, and its claim to be the quietest backpack blower was tested by Consumer’s Union, the publisher of *Consumer Reports.* As mentioned earlier, the sound level reported in *Consumer Reports* (1997) was 69.5 dBA, only slightly quieter than many other models on the market at the time. The City of Palo Alto (1998a, and Johnson, L., Palo Alto, pers. comm) tested the Echo PB46 LN and several other leaf blowers. In their study, the Echo PB46 LN tested at 70 dBA and the Maruyama BL 4500 SP tested at 69 dBA. However, the noisy Echo PB-400E, reported by the manufacturer at 74 dBA, also tested noisier at 77.6 dBA. Based on the City of

Palo Alto tests, then, the "quiet" leaf blowers were about half as loud as the "noisy" blower. Manufacturers are now discussing having their sound testing conducted by an independent third party, at least in part to address the concerns about differences between test results, in addition to revising the ANSI test method, as mentioned earlier.

3.3.6.2 Operator Noise Exposure. Noise levels at the leaf blower operator's ear were not made available to the Air Resources Board by manufacturers and little has been published on leaf blower noise exposure. The League for the Hard of Hearing (1999) publishes a fact sheet in which the noise level of a leaf blower is listed as 110 dBA. Clark (1991) reported that one model by Weedeater emitted a maximum level of 110-112 dBA and an equivalent A-weighted sound level (L_{eq}) of 103.6 dBA. This leaf blower model, however, is no longer available and these data may not be comparable to today's leaf blowers.

A more current study of leaf blower noise was located. Schulze and Lucchesi (1997), in an unpublished conference presentation, reported the range and average sound pressure level from four leaf blowers. The four leaf blowers were unidentified models from Craftsman, Weedeater, and Shop Vac.[7] The authors reported that 3 ft from the leaf blower, the SPLs ranged from 80 to 96 dBA, with an average value of 88 dBA, and concluded that leaf blower noise did not violate the OSHA permissible noise exposure limit. Given an average of 88 dBA and high of 96 dBA, however, it is more likely that at least two or three of the leaf blowers were measured at above 85 dBA, the Cal/OSHA action level for a hearing conservation program. At least one of the leaf blowers had an SPL above the Permissible Exposure Limit of 90; at 96 dBA, the operator would

[7]ARB was not able to obtain the specific models tested or actual SPLs for each model leaf blower.

be restricted to a 3 hr, 29 minute daily exposure without hearing protection. These results suggest that operators are probably exposed to noise levels above the Cal/OSHA action levels or permissible exposure limits.

In the absence of additional empirical data, noise exposures for operators can be estimated based on manufacturer-provided data on SPLs at 50 ft from the blower by applying the rule that each halving of the distance increases the sound pressure level by six decibels. It is reasonable to assume that the distance from the backpack blower to the operator's ear is between nine and 18 inches, and three feet is a good approximation of the distance from the operator's ear to the noise source for a hand held unit. Using this relationship, we calculate that an operator using a backpack leaf blower with a reported 75 dBA level at 50 ft would be exposed to maximum sound levels of 105 to 111 dBA. These exposure levels would restrict the operator without hearing protection to daily use of one-half to one hour. See Table 7 for additional examples:

Table 6. Sound Levels Exposures for Operator

Sound Level at 50 ft, dBA	At 3.125 ft (37.5 in), dBA	At 1.56 ft (18-19 in), dBA	At 0.78 ft (9 in), dBA
65	89	95	101
70	94	100	106
75	99	105	111

Finally, the Echo *Power Blower Operator's Manual* advises operators to wear hearing protection whenever the unit is used. The user is instructed that "OSHA requires the use of hearing protection if this unit is used 2 hours per day or more." This statement indicates that the operator would be exposed to an SPL of 100 dBA or more during use.

3.3.7 Use of Hearing Protection

No study was found that documented the incidence of hearing protection usage among operators of leaf blowers. Hearing protectors are widely available, and some manufacturers provide an inexpensive foam ear plug set with the purchase. More expensive custom molded ear plugs and ear muffs provide better protection than the moldable foam ear plugs, but again no data were available on usage. Two studies did examine the incidence of usage of hearing protection in other industries. In one study of 524 industrial workers, although 80.5% were provided with hearing protection devices, only 5.1% wore them regularly (Maisarah & Said 1993). In another study of metal assembly workers who worked in a plant where the average noise level was 89 dBA, only 39% of the men reported wearing hearing protection always or almost always (Talbott, et al. 1990).

3.3.8 Summary of Noise Emissions

While millions of Californians are likely exposed to noise from leaf blowers as bystanders, given the ubiquitousness of their use and the increasing density of California cities and towns, there is presently no way of knowing for certain how many are actually exposed, given the lack of studies. In contrast, it is likely that approximately 60,000 lawn and garden workers are daily exposed to the noise from leaf blowers. While anyone operating a leaf blower for more than 1-2 hrs daily should be using hearing protection, it is unlikely that even half of those exposed to noise over 100 dBA are protecting their hearing. Gardeners and landscapers, however, are very aware that noise is a problem, but perhaps they see it more as a hinderance to their ability to do their work, given that at least 100 cities in California ban or restrict the use of leaf blowers. Thus, purchases of quieter leaf blowers, based on manufacturer data, are increasing. Unfortunately, many models intended for the do-it-yourself homeowner are not as quiet as the commerical backpack models, and models targeted for the homeowner market usually do not advertise their noise rating.

4.0 REVIEW OF HEALTH EFFECTS

Leaf blower noise, exhaust and fugitive dust emissions, as discussed in previous sections of this report, are health concerns. Following is a discussion of health effects of particulate matter, carbon monoxide, unburned fuel, and noise. Particulate matter, carbon monoxide, and unburned fuel are part of exhaust emissions; particulate matter is also the major component of fugitive dust. Ozone is a pollutant that is formed in the atmosphere through chemical reactions of hydrocarbons (unburned fuel) and nitrogen oxides in the presence of ultraviolet light. Although not directly emitted, ozone is a pollutant of concern because leaf blowers emit hydrocarbons, which react to form ozone. The health effects of nitrogen oxides are not discussed as emissions from leaf blowers are relatively low, and any health effects would be negligible.

National Ambient Air Quality Standards have been set by the federal government to protect public health and welfare. In addition, California has State ambient air quality standards. These standards include a margin of safety to protect the population from adverse effects of pollutant exposure. The National Ambient Air Quality Standards and California standards are intended to protect certain sensitive and probable risk groups of the general population (Appendix C).

4.1 Particulate Matter Health Effects

Airborne PM is not a single pollutant, but rather is a mixture of many subclasses of pollutants with each containing many different chemical species (U.S. EPA 1996). Particles of 10 microns (μm) and smaller are inhalable and able to deposit and remain on airway surfaces. The smaller particles (2.5 μm or less) are able to penetrate deep into the lungs and move into intercellular spaces. The respirable particles owe their negative health impacts in part because of their long residence time in the lung, allowing chemicals time to interact with body tissues. ARB staff could not locate data on the specific chemical and physical make-up of leaf blower dust, thus only generic effects from the respirable fraction (particles 10 μm and smaller) are addressed.

Many epidemiologic studies have shown statistically significant associations of ambient PM levels with a variety of negative human health endpoints, including mortality, hospital admissions, respiratory symptoms and illness measured in community surveys, and changes in pulmonary mechanical function. Associations of both short-term, usually days, and long-term, usually years, PM exposure with most of these endpoints have been consistently observed. Thus, the public health community has a great deal of confidence in the conclusions of the many studies that PM is significantly associated with negative health outcomes.

There remains uncertainty, however, regarding the magnitude and variability of risk estimates for PM; the ability to attribute observed health effects to specific PM constituents; the time intervals over which PM health effects are manifested; the extent to which findings in one location can be generalized to other locations; and the nature and magnitude of the overall public health risk imposed by ambient PM exposure. While the existing epidemiology data provide support for the associations mentioned above, understanding of underlying biologic mechanisms is incomplete (U.S. EPA 1996)

4.2 Carbon Monoxide Health Effects

Carbon monoxide (CO) is a colorless, tasteless, odorless, and nonirritating gas that is a product of incomplete combustion of carbon-containing fuels. With exposure to CO, subtle health effects can begin to occur, and exposure to very high levels can result in death. The public health significance of CO in the air largely results from CO being absorbed readily from the lungs into the bloodstream, forming a slowly reversible complex with hemoglobin, known as carboxyhemoglobin. The presence of significant levels of carboxyhemoglobin in the blood reduces availability of oxygen to body tissues (U.S. EPA 1999c).

Symptoms of acute CO poisoning cover a wide range depending on severity of exposure, from headache, dizziness, weakness, and nausea, to vomiting, disorientation, confusion, collapse, coma and at very high concentrations, death. At lower doses, central nevous system effects, such as decreases in hand-eye coordination and in attention or vigilance in healthy individuals have been noted (Horvath et al. 1971, Fodor and Winneki 1972, Putz et al. 1976, 1979, as cited in U.S. EPA 1999c). These neurological effects can develop up to three weeks after exposure and can be especially serious in children.

National Ambient Air Quality Standards have been set to protect public health and welfare (see Appendix C for a listing) and are intended to protect certain sensitive and probable risk groups of the general population. The sensitive and probable risk groups for CO include anemics, the elderly, pregnant women, fetuses, young infants, and those suffering from certain blood, cardiovascular, or respiratory diseases. People currently thought to be at greatest risk from exposure to ambient CO levels are those with ischemic heart disease who have stable exercise-induced angina pectoris (cardiac chest pain) (ARB 1992a, U.S. EPA 1999c).

4.3 Unburned Fuel Health Effects

Some toxic compounds are present in gasoline and are emitted to the air when gasoline evaporates or passes through the engine as unburned fuel. Benzene, for example, is a component of gasoline. Benzene is a human carcinogen and central nervous system depressent (ARB 1997b). The major sources of benzene emissions in the atmosphere are from both unburned and burned gasoline. The amount of benzene in gasoline has been reduced in recent years through the mandated use of California Reformulated Gasoline (ARB undated fact sheet, on the Internet at: http://arbis.arb.ca.gov/cbg/pub/cbgbkgr1.htm). Other toxic compounds that are emitted from vehicle exhaust incluce formaldehyde, acetaldehyde, and 1,3-butadiene. Acetaldehyde is a probable human carcinogen (Group B2) and acute exposures lead to eye, skin, and respiratory tract irritation (ARB 1997b). 1,3-Butadiene is also classified as a probable human carcinogen, is mildly irritating to the eyes and mucous membranes, and can cause neurological effects at very high levels (ARB 1997b). Formaldehyde is highly irritating to the eyes and respiratory tract and can induce or exacerbate asthma. It is also classified as a probable human carcinogen (Group B1) (ARB 1997b). As with benzene, emissions of these toxic air contaminats from gasoline exhaust have been reduced by the use of California Reformulated Gasoline.

4.4 Ozone Health Effects

Ozone is a colorless, odorless gas and is the chief component of urban smog. It is by far the state's most persistent and widespread air quality problem. Ozone is formed from the chemical reactions of hydrocarbons and nitrogen dioxide in the presence of sunlight. Leaf blowers emit substantial quantities of hydrocarbons, primarily from unburned fuel, which can react to form ozone. Ozone is a strong irritant and short-term exposures over an hour or two can cause constriction of the airways, coughing, sore throat, and shortness of breath. Ozone exposure may aggravate or worsen exisitng respiratory diseases, such as emphysema, bronchitis, and astham. Chronic exposure to ozone can damage deep portions of the lung even after symptoms, such as coughing, disappear. Over time, permanent damage can occur in the lung, leading to reduced lung capacity.

4.5 Noise Health Effects

The literature on health effects of noise is extensive. In this section of the report, staff have relied heavily on the reports by the U.S. EPA (1974, 1978, 1979, 1981a), the National Institutes of Health Consens Statement (NIH 1990), a review article by Alice Suter (1991), an edited book on the biological effects of noise (Prasher and Luxon 1998), and Karl Kryter's handbook of noise (1994), in addition to original research articles.

In summary, exposure of adults to excessive noise results in noise-induced hearing loss that shows a dose-response relationship between its incidence, the intensity of exposure, and duration of exposure; and noise-induced stimulation of the autonomic nervous system, which reportedly results in high blood pressure and cardiovascular disease (AAP 1997). In addition there are psychological effects. The following subsections will first discuss noise-induced hearing loss, followed by impacts on the fetus and newborn, then physiological stress-related effects. Finally, we will discuss impacts on sleep, communication, effects of performance and behavior, annoyance, and effects on wildlife and farm animals. These are not perfect divisions between discreet affects: sleep-deprivation, for example, can lead to stress, elevated blood pressure, and behavioral changes; psychological effects lead to physiological changes, especially if the annoyance is repeated and uncontrollable. But first, before discussing effects, the reader should have an understanding of how the ear functions.

4.4.1 Hearing and the Ear

A detailed discussion of the ear's anatomy and the mechanism by which we hear is beyond the scope of this report, but a basic level of understanding is necessary so that later discussions of damage to hearing will be better understood. For further information, the reader is referred to any basic acoustics or biology text.

The ears are paired sensory organs that serve two functions, to detect sound and to maintain equilibrium; only sound detection will be addressed in this report. The ears are composed of the external ear, middle ear, and the inner ear. With the assistance of the external ear in collecting and focusing sound, vibrations are transmitted to the middle ear via the ear canal and the eardrum. The vibrations of the eardrum are transmitted by the bones of the middle ear to the fluid-filled sensory organ of the inner ear, the cochlea. As the fluid of the inner ear vibrates, the hair cells located in the cochlea bend, stimulating sensory receptors, and leading to nerve impulses being transmitted to the brain via the auditory nerve. The greater the hair cell displacement, the more sensory receptors and neurons are stimulated, resulting in the perception of an increase sound intensity.

Hearing loss can result from damage or growths in any portion of the ear and the part of the brain that processes the nerve impulses. Damage to the outer and middle ear result in "conductive" hearing loss, in which case the vibrations could still be perceived and processed if they can be transmitted by another means to the inner ear. Damage to the inner ear and auditory nerve result in "sensorineural" hearing loss. Sensorineural hearing loss can be temporary, if the body's mechanisms can repair the damage, but cumulative inner ear damage will result in permanent hearing loss. Aging, diseases, certain medications, and noise cause the majority of sensorineural hearing loss, which is not reversible by surgery or medication, and is only partially helped by hearing aids.

4.4.2 Noise-Induced Hearing Loss

Roughly 25% of all Americans aged 65 and older suffer from hearing loss. Contrary to common belief, hearing loss is not part of the natural aging process, but is caused by preventable, noise-induced wear and tear on the auditory system (Clark and Bohne 1999). Noise-induced hearing loss develops gradually over years and results from damage to the inner ear. Sensory cells within the cochlea are killed by exposure to excessive noise. These cells do not regenerate but are replaced with scar tissue. After weeks to years of excessive noise, the damage progresses to the point where hearing loss occurs in the high-frequency range and is detectible audiometrically; speech comprehension is not usually affected and so at this level hearing loss is usually not noticed by the individual. Finally, with continued exposure, the hearing loss spreads to the lower pitches necessary to understand speech. At this point, the impairment has proceeded to the level of a handicap and is quite noticeable. The damage, however, is not reversible and is only poorly compensated for by hearing aids.

There is considerable variability among individuals in susceptibility to hearing loss. Based on major field studies conducted in the late 1960s and early 1970s, the U.S. EPA suggested that a 24-hour equivalent sound level of 70 dBA would protect 96% of the population, with a slight margin of safety, from a hearing loss of less than five dBA at 4000 Hz (U.S. EPA 1974). This 24-hour, year-round equivalent sound level is based on a forty-year work-place noise level exposure (250 working days per year) of 73 dBA for eight hours and 60 dBA for the remaining 16 hours.

The National Institute for Occupational Safety and Health reviewed the recommended occupational noise standard more recently (NIOSH 1996) and reaffirmed its recommended exposure limit of 85 dBA for occupational noise exposure. The report concluded that the excess risk of developing occupational noise-induced hearing loss for a 40-hr lifetime exposure at 85 dBA is 8%. In comparison, the OSHA regulation [29 CFR §1910.95] allowing a 90 dBA permissible exposure limit results in a 25% excess risk of developing hearing loss. The OSHA regulation, however, has not been changed to reflect the recommendation of the National Institute for Occupational Safety and Health.

NIOSH also recommended changing the exchange rate, which is the increment of decibels that requires the halving or doubling of exposure time, from the OSHA mandated 5 dBA to 3 dBA. This would mean that if the worker was permitted to be exposed to 85 dBA unprotected for 8 hr, then a noise exposure level of 88 dBA would be limited to 4 hr per day. The 3-dBA exchange rate is supported by acoustics theory, and by national and international consensus. OSHA, however, continues to mandate the 5 dBA exchange rate in its regulations.

4.4.3 Effects on the Fetus and Newborn

The human cochlea and peripheral sensory end organs, which make up the ear, complete their normal development by 24 weeks of gestation (AAP 1997). The sense of hearing matures from that point as the nervous system matures. Sound transmits well through the watery environment of the uterus, and thus the fetus is exposed to noise throughout the second half of its development. Studies have found that exposure to excessive noise during pregnancy, such as received when the mother's occupation exposes her to noise, may result in high-frequency hearing loss in newborns, and may also be associated with prematurity and low birth weight. For newborns, studies have found that exposure to noise in the Neonatal Intensive Care Unit may result in damage to the cochlea, and thus hearing loss, and may disrupt normal growth and development of premature infants.

The American Academy of Pediatrics (1997) recommends further research to conclusively determine health effects of noise exposure on pregnant women and their fetuses and infants. Pediatricians are encouraged to screen infants for noise-induce hearing loss when their mothers are occupied in jobs that require the wearing of protective hearing devices. The Academy asks the National Institute of Occupational Safety and Health to conduct research on noise exposure during pregnancy and recommends that the OSHA consider pregnancy when setting occupational noise standards.

4.4.4 Non-Auditory Physiological Response

In addition to hearing loss, other physiologic and psychologic responses resulting from noise have been noted and are termed "non-auditory" effects. Noise is assumed to act as a non-specific biological stressor, eliciting a "fight or flight" response that prepares the body for action (Suter 1991). Noise could, therefore, cause multiple changes in the body's autonomic nervous system and influence behavior. Research has, therefore, focused on effects of noise on blood pressure and changes in blood chemistry indicative of stress. Despite decades of research, however, the data on effects are inconclusive. While many studies have shown a positive correlation between hearing loss, as a surrogate for noise exposure, and high blood pressure, many have shown no correlation (Suter 1991; Kryter 1994).

Problems with conducting studies of the health of people working in noisy industries include the difficulty of controlling for variables that may also be correlated with the effect one is trying to correlate with noise exposure. Kryter (1994) highlights psychological variables that will also stimulate the autonomic nervous system. These include work conditions in a noisy industry, which may be inherently unsafe, raising stress levels. In addition, the noise itself may interfere with the ability to carry out work, thus increasing a worker's anxiety about work performance.

Suter (1991) concludes her review of the evidence with the statement that "[m]ost effects appear to be transitory, but with continued exposure some effects have been shown to be chronic in laboratory animals. Probably the strongest evidence lies in the cardiovascular effects. However, many studies show adverse effects, while many other show no significant differences between experimental and control populations." The National Institutes for Occupational Safety and Health (1996) has called for further research to define a dose-response relationship between noise and non-auditory effects, such as hypertension and psychological stress.

4.4.5 Interference with Communication

The inability to communicate can degrade the quality of living directly, by disturbing social and work-related activities, and indirectly, by causing annoyance and stress. The U.S. EPA (1974), in developing its environmental noise levels, determined that prolonged interference with speech was inconsistent with public health and welfare. Noise that interfers with speech can cause effects ranging from slight irritation to a serious safety hazard (Suter 1991), and has been shown to reduce academic performance in children in noisy schools, as reviewed by Kryter (1994). The U.S. EPA (1994), therefore, developed recommended noise levels which are aimed at preventing interference with speech and reduced academic performance. An outdoor yearly average day-night sound level of 55 dBA permits adequate speech communication at about 9-10 ft, and also assures that outdoor noise levels will not cause indoor levels to exceed the recommended level of 45 dBA.

4.4.6 Interference with Sleep

It is common experience that sound rouses sleepers. Noise that occurs when one is trying to sleep not only results in repeated awakenings and an inadequate amount of sleep, but is also annoying and can increase stress. Noise that is below the level that awakens, however, also changes the sleep cycle, reduces the amount of "rapid eye movement" sleep, increases body movements, causes cardiovascular responses, and can cause mood changes and performance decreases the next day (Suter 1991). The U.S. EPA's indoor average yearly day-night level of 45 dBA, which translates into a night time average sound level of 35 dBA, is thought to protect most people from sleep disturbance.

An average sound level, however, does not adequately account for peak sound events that can awaken and disturb sleep. Continuous noise has a significantly smaller sleep disturbance effect than intermittent noise. Research has found that subjects in sleep laboratory experiments will gradually reduce the number of awakenings throughout the night in response to noise, but other physiological changes, including a momentary increase in heart rate, indicative of arousal do not change. The question is whether physiological arousal, short of awakening, has a negative health effect. While study results are inconclusive on this issue, it is clear that noise above a certain level, about 55 dBA L_{eq}, according to Kryter, 1994, will awaken people, even after long periods of repeated exposures. Repeated awakenings reduce feelings of restedness and cause feelings of annoyance, leading to stress responses and associated health disorders.

4.4.7 Effects on Performance and Behavior

The working hypothesis in this area has been that noise can cause adverse effects on task performance and behavior at work, in both occupational and non-occupational settings. Results of studies, however, have not always been as predicted. Sometimes noise actually improves performance, and sometimes there are no measurable differences in performance between noisy and quiet conditions (Suter 1991). Kryter (1994) concluded that masking by noise of other auditory signals is the only inherent auditory variable responsible for observed effects of noise on mental and psychomotor tasks.

A frequently-cited study comprising two experiments examined “helping behavior” in the presence and absence of noise. Mathews and Canon (1975) tested the hypothesis that high noise levels may lead to inattention to the social cues that structure and guide interpersonal behavior. In a laboratory study in which subjects did not know they were being studied, they found that fewer persons were willing to help someone who had “accidentally” dropped materials when background noise levels were 85 dB than when they were 65 dB or 48 dB. In a subsequent field study, similar results were demonstrated with background noise from a lawn mower. Initially, subjects were tested as to their willingness to help a man who had dropped books and papers while walking from his car to a house; in this test, helping behavior was low both in ambient (50 dB) and high (87 dB) noise conditions. When the test was repeated with a cast on the arm of the man who dropped the books, helping behavior was high under ambient noise (80%) and low under high noise (15%) conditions. These and other studies lead to the conclusion (Suter 1991) that even moderate noise levels can increase anxiety, decrease the incidence of helping behavior, and increase the likelihood of hostile behavior.

4.4.8 Annoyance and Community Response

Annoyance is measured as an individual response to survey questions on various environmental factors, such as noise (Suter 1991). The consequences of noise-induced annoyance are privately held dissatisfaction, publicly expressed complaints, and possibly adverse health effects. Various U.S. government agencies began investigating the relationships between aircraft noise and its effect on people in the early 1950's. On reviewing studies to date, the U.S. EPA concluded that there was no evidence of public complaints if the average yearly day-night sound level was less than 50 dB (U.S. EPA 1974).

Fidell et al. (1991) reveiwed and synthesized the relationship between transportation noise and the prevalence of annoyance in communities based on over 30 studies. The relationship is an exponentially increasing function, with less than 10% of respondents reporting themselves to be highly annoyed at noises under an average day-night sound level of 56 dB. Fifty percent responded they were highly annoyed at sound levels approaching 79 dB, and nearly every person was highly annoyed at sound levels above 90 dB. Based on over 450 data points, the best-fit equation for the quadratic function was found to be:

$$\%\text{ highly annoyed} = 0.036L_{dn}^{2} — 3.2645L_{dn} + 78.9181.$$

Suter (1991) concluded that throughout decades of study, community annoyance has been positively correlated with noise exposure level, and that although variables such as ambient noise level, time of day, time of year, location, and socioeconomic status are important, the most important variable is the attitude of the affected residents. Kryter (1994) further elaborates that interference by noise, and the associated annoyance, depends on the activity of an individual when the noise event occurs, and the intensity and duration of the noise. People have different beliefs about noise, which are also important. Those most annoyed share similar beliefs that the noise may be dangerous, is probably preventable, are aware that non-auditory effects are associated with the noise source, state they are sensitive to noise, and believe that the economic benefit represented by the source is not important for the community (Fields 1990).

4.4.9 Effects of Noise on Animals

Kryter (1994) reviewed studies on the effects of noise both on wildlife and farm animals. None of these studies examine noise-induced hearing loss, but rather looked at effectsof noise on litter size, prevalence of wildlife, and milk production. Most of the studies were conducted to examine the effects of airport noise, including noise from landings and takeoffs and sonic booms near commercial and military airports, and noise from construction activities during laying of pipelines across wilderness areas. Negative impacts on wildlife and farm animals, due to noise, were not supported by the studies. In the airport studies, the absence of human activities in the areas surrounding the high noise exposure zones appeared to be more important than noise, resulting in abundant wildlife. Farm animals exposed to frequent sonic booms showed little or no negative effects, again using such criteria as reproduction, milk production, and growth rate.

5.0 POTENTIAL HEALTH AND ENVIRONMENTAL IMPACTS OF LEAF BLOWERS

Leaf-blower operators and bystanders have two different types of exposures to exhaust and fugitive dust emissions: exposures that occur on a regional basis and exposures that occur when one is within a short distance of the leaf blower. Regional exposures are those exposures to air pollution that occur as a result of leaf blowers contributing to the basin-wide inventory of ozone, carbon monoxide, particulates, and toxic air pollutants. While leaf blowers contribute a small percentage to the air basin-wide air pollution, they are nonetheless a source of air pollution that can be, and is, controlled through exhaust emission standards, as detailed in section 3.1.3.

The second type of exposure is of greater concern. Lawn and landscape contractors, homeowners using a leaf blower, and those in the immediate vicinity of a leaf blower during and shortly after operation, are exposed to potentially high exhaust, fugitive dust, and noise emissions from leaf blowers on a routine basis. The ARB staff have not located much data on how often, how long and at what concentrations these exposures occur. The ARB off-road model assumes that each commercial leaf blower is used for 275 hr/yr, and each residential leaf blower is used for 10 hr/yr, which does not address the annual use of leaf blowers by the operator.

A consumer products manufacturer (Anon. 1999), who asked to remain anonymous for this report, recently surveyed 100 lawn and landscape contractors in the Southern California area. The survey found that the average use of commercially-owned leaf blowers by operators was three hours per day. Assuming a five day work-week, then, the average commercial gardener, then, would use a leaf blower for 780 hours per year. No similar data were collected for homeowners doing their own work, however. As staff do not expect homeowners to possess more than one leaf blower at a time, unlike commercial gardeners who many own more than one leaf blower to ensure that they always have one available for work, the ARB estimate of 10 hr/yr usage per leaf blower is probably close to the annual operator exposure.

Because of the highly speculative nature of the data on operator and bystander exposure time, staff have been unable to develop estimates of the quantities of chemicals individuals could be exposed to per amount of time. Instead, impacts are presented somewhat qualitatively, with recommendations for appropriate personal protection or controls from hazards that staff have found to be significant. So that the reader can better picture the magnitude of different impacts for exhaust and fugitive dust emissions, staff have estimated the amount of still air the emissions from ten minutes of leaf blower operation would have to be mixed in to prevent a local, transitory exceedance of the relevant national ambient air quality standards. The PM standards, however, are not generally short term exposure standards, but have been selected as the best surrogate for short term exposure standards. The following estimates for exhaust and fugitive dust exposures, then, have no objective significance, in and of themselves, but are presented for comparative purposes.

5.1 The Worker

In this section, data on impacts are presented that apply to the commercial leaf blower operator, which is a person who regularly uses the leaf blower in the course of a landscaping or gardening job. Staff assume that a commercial leaf blower operator will use equipment with a higher horsepower than a residential, or homeowner, operator, and that most of the work will consist of operating the leaf blower in areas where the silt loading values are high.

5.1.1 Exhaust Emissions

The "typical" leafblower owned and operated by commercial lawn and landscape contractors, with an average horsepower of three and a load factor of 50%, will produce the emissions for a ten minute usage as shown in Table 7. Ten minutes is considered to be a reasonable estimate of the time it might take to clean an average yard. If the actual usage is greater or less than ten minutes, the data presented in Table 7 can be adjusted accordingly.

Table 7. Leaf Blower Emissions and Mixing Space for the Operator, 3 hp average and 50% load factor, 1999

	Exhaust Emissions	Ten min. of Exhaust Emissions	Amount of Mixing Space Necessary to Not Exceed the NAAQS[8]
Hydrocarbons	199.25 g/hr	33.21 g	NA[9]
Carbon Monoxide	423.54 g/hr	70.59 g	1777 m^3
Particulate Matter	6.42 g/hr	1.07 g	7133 m^3
Fugitive Dust	---	102 g	680,000 m^3

For CO, the 70.59 g emitted in ten minutes would require mixing in 1777 m3 air in order not to exceed the NAAQS 1 hr standard for CO of 35 ppm, assuming that all of the CO remains in the immediate area, and that the person being exposed breathes this air for 1 hour. The amount of air in 1777 m3 is comparable to the amount of air that would fill a cube 12.1 m, or 39.7 ft, on each side. As discussed above, this estimate does not permit a determination of the health impacts of the exposure to CO. These data, however, do suggest that the relatively large amount of CO emitted directly into the air space surrounding the operator could result in the inhalation of an

[8]National Ambient Air Quality Standard

[9]No relevant NAAQS exists for "hydrocarbons" as this is a catch-all category for many chemicals.

unhealthful dose. Staff recommends that further research is warranted to determine exposures and related health impacts from small, two-stroke engine emissions.

For the PM10 that is directly emitted from exhaust emissions, the air space necessary for mixing in order not to exceed the 24-hour standard for PM10 is larger than that for CO, comprising an amount of air equivalent to a cube 19.2 m, or 63.2 ft, on each side. PM emissions from the blown dust, however, dwarf the PM emissions from exhaust.

5.1.2 Fugitive Dust

For fugitive dust, ten minutes of use during commercial use would exposure the operator to significant amounts of PM (Table 7). A cube of air 88 m, or 288.4 ft, on each side would be equivalent to the 680,000 m^3 of air that would be needed to dilute the PM10 sufficiently to avoid exceeding the 24-hour national ambient air quality standard. While leaf blower operators would not be expected to spend significant amounts of time within such a particulate cloud, the day-in-day-out exposure to this much PM10 could have serious health consequences in the long-term. Short-term exposures of one to two days to high levels of PM can lead to coughing and minor throat irritation. Long-term exposures have shown statistically significant associations of ambient PM levels with a variety of negative human health outcomes, as discussed previously. These data strongly suggest that professional leaf blowers operators, and those regularly working within the envelope described above, should wear a face mask effective at filtering PM from the air.

5.1.3 Noise

The potential health impacts of leaf blowers on workers from noise center on noise-induced hearing loss. Two factors contribute to hearing loss in typical career gardeners: the high sound pressure levels emitted by leaf blowers at the level of the operator’s ear, and the infrequent use of hearing protection. While we cannot calculate the percentage of workers who will experience noise-induced hearing loss without additional data, these two factors are likely responsible for hearing loss in a high percentage of workers, although they may not notice any hearing loss until many years have passed. Although no studies exist documenting hearing protection usage in gardeners, usage is low in other industries and there is no reason to assume gardeners behave differently. In addition to hearing loss experienced by the worker, pregnant women operating leaf blowers put their fetuses at risk of developing hearing loss, and noise exposure may also lead to low birth weight and prematurity from the in-uterus exposure. No hearing protection program has been devised for the fetus.

In order to reduce hearing loss, employers should require that employees use hearing protection. State and local health and enforcement agencies should promote hearing protection in campaigns targeted at professional landscapers and gardeners. Hearing loss is gradual, and may become obvious only years after the exposure has ceased. While gardeners may feel they are somehow immune to hearing loss, which is a typical attitude of young, healthy workers, staff has concluded that noise-induced hearing loss is a certainty for the majority of professional leaf blower operators.

5.2 The Public-at-Large

Those who are not working in landscaping and gardening fall into two categories: homeowners doing their own gardening and bystanders. Homeowners who chose to use a leaf blower likely experience relatively low-level exposures which they control. Bystanders may experience low or high exposures, depending on the nature of the exposure. Bystanders, however, almost never have chosen to be exposed to the exhaust, dust, and noise emissions of the leaf blower. Thus their attitude toward the leaf blower is likely very negative and they may be highly annoyed by the exposure. In addition, staff have received letters from some people, and read testimonials on Internet web-sites, concerning acute symptoms, such as asthma and allergies, exhibited by sensitive individuals to relatively limited exposures. These symptoms have not been evaluated in this report as they are anecdotal and unable to be substantiated. It is important, nevertheless, to acknowledge that some individuals may be very sensitive to the emissions from leaf blowers and unable to tolerate exposures that do not seem to bother other individuals.

In addition to homeowner-leaf blower operators and bystanders who are in the vicinity of leaf blower operation, everyone is exposed to a small degree to air pollution that results from exhaust and dust emissions from leaf blowers. This report does not quantify those exposures, but the ARB does regulate exhaust emissions from leaf blowers, as from most other sources of air pollution. As discussed elsewhere, all sources of air pollution need to be reduced in order that Californians can breath clean air.

5.2.1 Exhaust Emissions

The “typical” leafblower owned and operated by a homeowner for private residential use is assumed to have an average horsepower of 0.8 and a load factor of 50%, based on the ARB off-road emissions model. Using the same methods as above produces the emissions shown in Table 8.

Table 8. Leaf Blower Emissions and Mixing Space for the Homeowner, 0.8 hp average and 50% load factor, 1999

	Exhaust Emissions	Ten min. of Exhaust Emissions	Amount of Mixing Space Necessary to Not Exceed the NAAQS[10]
Hydrocarbons	56.7 g/hr	9.45 g	NA[11]
Carbon Monoxide	119.2 g/hr	19.86 g	500 m^3
Particulate Matter	1.44 g/hr	0.24 g	1,600 m^3
Fugitive Dust	---	1.8 g	12,000 m^3

For comparison, for CO the mixing space necessary to avoid exceeding the standards is equivalent to a cube of air 8 m, or 26 ft, on each side. For all emissions, exposures are considerably lower in a residential setting than in a commercial setting. The data presented in Table 8 do not address bystander exposures, for which we have even less data than for leaf blower operators, and again it is not possible to determine health impacts.

5.2.2 Fugitive Dust Emissions

For fugitive dust (Table 8), 1.8 g of PM10 emitted in ten minutes would need to be mixed in a volume of 12,000 m^3 of air in order to avoid exceeding the 24-hour standard for PM10. This is an amount of air equivalent to a cube 22.9 m, or 75.1 ft, on each side. As with the commercial exposure, this is a potentially hazardous exposure, but because the homeowner is likely using leaf blowers for a very short time each week, the concern is much lower than for commercial

[10]National Ambient Air Quality Standard

[11]No relevant NAAQS exists for “hydrocarbons” as this is a catch-all category for many chemicals.

gardeners. Still, staff would recommend that even homeowners wear a dust filtering mask when using a leaf blower.

5.2.3 Noise

The homeowner who uses a leaf blower for a brief amount of time each week or two is unlikely to experience noise-induced hearing loss. The cummulative exposure to many recreational sources of noise, however, is likely to great enough to impact hearing (Clark 1991). Those who regularly use noisy power equipment should be in the habit of using hearing protection.

The likelihood of a bystander exposed to leaf blower noise on an irregular basis experiencing hearing loss is low. The potential health impacts from leaf blowers on bystanders that are likely more important include interefence with communication, sleep interuption, and annoyance. Each of these impacts may in turn lead to stress responses, although research has not conclusively tied chronic exposures with any particular adverse health outcome. Although interference with communication, sleep interuption, and annoyance may not seem to be serious impacts, they are important quality of life issues for many people. At least 100 municipalities in California have restricted or banned the use of leaf blowers within city limits in response to people who object to the loud noise of leaf blowers interupting their lives.

6.0 SUGGESTED FUTURE RESEARCH

6.1 Exhaust Emissions

The ARB has an active research program to determine exhaust emissions from engines that it regulates. Existing and future exhaust emission control standards will continue to require that manufacturers reduce emissions from the small off-road engines found in leaf blowers. Staff conducts periodic reviews of technology to determine whether further emission reductions are possible. For example, the ARB has recently awarded a contract to the Southwest Research Institute to conduct research entitled “Particulate Emissions from Marine Outboard Engines, Personal Watercraft and Small Off-Road Equipment.” The objectives relevant to leaf blower technology are (1) to measure the emissions from two-stroke engines used in small off-road equipment, with an emphasis on PM emissions and polycyclic aromatic hydrocarbon levels; and (2) to determine particle size distribution and mutagenic toxicity of the PM. The contractor will obtain and test five engines typically used in leaf blowers or similar off-road equipment, and staff have recommended that engines used in leaf blowers be among those chosen.

In addition to this study, staff has identified investigation into small off-road engine deterioration as an area for future research; engine deterioration causes emissions to increase with engine usage. In general, annual usage data, both for the leaf blower equipment and for the operator, would be helpful. As discovered during the course of this report, data on the annual usage of the equipment may not correlate well with how long an operator, commercial or residential, uses the equipment throughout the year.

6.2 Fugitive Dust

ARB staff found a fundamental lack of information on the nature and quantity of fugitive dust blown, or resuspended, by leaf blowers. AeroVironment attempted to calculate the amount of fugitive dust resuspended by leaf blowers in the SCAQMD as a first order approximation. Empirical data are needed, however, as calculations only go so far. Any study would need to consider a large number of variables, such as substrate, humidity, time of year, and type of materials being moved by the leaf blower. Ideally, as part of a future research project, one would want to first quantify the emissions in actual use by:

(1) inventorying the types of surfaces cleaned by leaf blowers statewide, and by air district,

(2) determining the silt loading for surfaces that are cleaned, and

(3) performing source testing to determine the amount of PM30, PM10 and PM2.5 entrained in the air, and to determine the "exposure envelope" associated with leaf blower usage.

This information could then be used to calculate more accurate estimates of dust associated with leaf blower usage.

In addition to quantifying emissions, it would also be important to determine what is in the dust. This information, however, would not apply only to leaf blowers, but would reflect what is in dust that is resuspended by wind from any source. Presently, chemical speciation data are available for sources such as paved and unpaved roadways. For leaf blowers, we should also examine the make-up of dust from lawns, sidewalks, parking lots, and flower beds. In addition to chemical speciation, it would also be useful to analyze the dust for the presence of herbicides, pesticides, bacterial endotoxins, and other toxins.

6.3 Noise Emissions

The investigation and reduction of noise emissions is not part of the ARB's authority or mission, although noise was investigated by the ARB at the requestion, through SCR 19, of the California Legislature. Traditionally, noise control and abatement has been a local function, although a state Office of Noise Control did exist for a short time; the Office was housed within the Department of Health Services. The following suggestions for noise related research, then, are offered with comment as to the appropriate agency for carrying out the research.

Quantifying noise exposure might be appropriate for the ARB to conduct only as a part of a larger effort that would be aimed at better understanding the number of leaf blowers, their hours of use, and differentiation between residential and commercial use. In addition, the Office of Environmental Health Hazard Assessment may be able to assist with preparing a noise exposure report, just as they have prepared reports on exposures to toxic air contaminants. Otherwise, each suggested research item is more appropriately conducted by the Department of Health Services Occupational Health Branch or a state of federal agency dedicated to worker issues.

(1) Quantification of the number of Californians affected by noise and noise exposure levels. The purposes of this study would be two-fold: First, to assess the number of workers who are exposed to leaf blower noise, the number of hours they are exposed daily, and their daily noise dose and exposures. Second, to determine the number of people exposed non-occupationally to leaf blower noise, average noise exposures, frequency of exposure (e.g., daily, weekly), and how they are affected (e.g., annoyed, interference with sleep or communication).

Agencies potentially responsible: *ARB; Office of Environmental Health Hazard Assessment; California Department of Health Services Occupational Health Branch.*

(2) Evaluation of hearing loss in gardeners, with emphasis on those who use leaf blowers as a part of their work. The purpose of this study would be to evaluate, more specifically, the incidence of noise-induced hearing loss in occupationally exposed gardeners. Non-occupational exposure to noise would also need to be assessed.

Agencies potentially responsible: National Institutes for Occupational Safety and Health; California Department of Health Services Occupational Health Branch.

(3) Incidence of use of personal protective equipment by gardeners. The purpose would be to determine the frequency of use and types used of personal protective equipment (PPE) such as hearing protectors, dust “comfort” masks, and eye protection. This study should be conducted with an education component, with the goal of increasing the use of PPE.

Agencies potentiall responsible: California Occupational Safety and Health Administration; California Department of Health Services Occupational Health Branch.

7.0 FUTURE LEAF BLOWER TECHNOLOGIES

7.1 Engine Technologies That Reduce Exhaust Emissions

For the most part manufacturers have met the 1995-1999 emissions standards by calibrating their engines to use less fuel, and improving production practices to include tighter tolerances. With implementation of more stringent standards in the 2000 model year will come more advanced technologies. Various manufacturers have indicated that they will meet the 2000 model-year standards with either small four-stroke engines that have been specifically designed for light-weight and multi-positional use, two-stroke engines with direct fuel injection, or two-stroke engines with stratified scavenging. Moreover, virtually all manufacturers have indicated that they will provide complying products, though not all have been specific about the technologies they plan to use. The various technologies represent a variety of ideas, but ultimately all would reduce the amount of fuel delivered to the combustion chamber. The technologies are briefly described below.

7.1.1 Four-Stroke Engines

Four-stroke engines possess the advantage that the exhaust stroke expels very little unburned fuel, so engine-out HC emissions are much lower than a two-stroke engine. This is because exhausting the spent gases and refilling the cylinder with a fresh air/fuel charge happens sequentially in a four-stroke engine, but simultaneously in a two-stroke engine. In the past, four-stroke engines have not been able to operate multi-positionally, because of engine lubrication problems, so four-strokes have not traditionally been used in handheld equipment. Ryobi and Honda, however, are two companies that have developed handheld four-stroke engines for the

2000 standards. Honda has indicated that it intends to use its engine in blowers and Ryobi offers attachments that can convert a string trimmer to a blower.

7.1.2 Fuel-Injected Two-Stroke Engines

Fuel injection provides better control of the amount and the timing of fuel entering the cylinder. By limiting the fuel admitted to the amount necessary for combustion, and timing fuel introduction to limit the fuel exiting with the exhaust gases, less unburned fuel exits the engine. The loss of unburned fuel is the primary cause of the high HC emissions from two-stroke engines; up to one third of the fuel going into a conventional two-stroke engine exits the exhaust pipe unburned. Tanaka is a company that has developed a fuel-injected two-stroke engine, partially through funding provided by the ARB's Innovative Clean Air Technologies program.

7.1.3 Stratified Scavenging Two-Stroke Engines

Stratified scavenging refers to a system that prevents mixing of the incoming fuel with the exhaust gas by injecting a layer ("strata") of air between the two. The result is that less of the fresh (unburned) fuel escapes, and HC emissions are dramatically reduced. Test results indicate that the technology can easily meet the 2000 standard. As put into practice by Komatsu Zenoah, manufacturer of the Red Max line of blowers, the stratified scavenging engine retains all the advantages of a conventional two-stroke: light-weight, high power output, and relatively simple design. The result is an engine that operates nearer to the chemically balanced air/fuel ratio, which also translates into improved fuel economy.

7.1.4 Two-Stroke Engine with Compression Wave Technology

This technology involves a compressed-air-assisted fuel injection system that eliminates the unburned fuel during the scavenging process of the exhaust portion of the two-stroke cycle.

Engines utilizing this technology retain much of the conventional two-stroke design and hardware, and although the fuel metering system needs to be designed to perform with the engine's needs, it reportedly does not need to provide high precision in timing or in spray quality.

The thrust behind the technology is a compression wave, which causes the fuel and air in the cylinder to be greatly disturbed, in effect functioning as a shock wave. This atomizes the fuel and mixes it more thoroughly with the air. In addition, the compression wave helps keep fuel from sticking to the cylinder. According to the U.S. EPA regulatory impact analysis for its small engine regulatory efforts (EPA 1999a), the system as developed by John Deere Consumer Products includes an "accumulator" which collects and temporarily stores compressed air scavenged from the crankcase. The piston compresses the air in the crankcase on the piston's downward stroke. The fuel injection system uses the piston head to open and close its ports. With respect to engine power, John Deere Consumer Products states that the engine power remains nearly the same as the engine without the technology. The technology is planned for production on John Deere Consumer Products equipment in California in 2000.

7.1.5 Two-Stroke Engines with Catalysts

In addition to the above technologies, some manufacturers currently offer equipment with catalytic converters; in fact, the presence of a catalyst is sometimes used as a marketing feature in Europe. As with an automobile, the catalyst assists the conversion of hydrocarbons and carbon monoxide to more benign compounds.

7.2 Sound Reduction Technologies

Leaf blower manufacturers are developing new designs to both reduce the amount of noise from leaf blowers and change the quality of sound to make it less irritating (L. Will, Echo, pers.

comm.). The methods range from quieting the engine noise by insulating the engine compartment to changing the design of the fan. Significant sound comes from the fan itself, and thus new fan designs have the potential to change both the loudness and sound quality.

Electric leaf blowers are usually significantly quieter than gasoline-powered leaf blowers because of the absence of the engine noise. The Los Angeles City Council requested that its Department of Water and Power develop a quieter leaf blower, and a contract was awarded to AeroVironment. The firm developed a prototype electric, battery-powered blower that should be produced in small quantities for testing late in 1999 or early in 2000 (L. Johnson, LADWP, pers. comm). This blower is discussed more in section 7.4 below.

7.3 Methanol

The use of methanol as a fuel for leaf blowers came about following ordinances to ban the use of "gas-powered" leaf blowers. Some parties have undertaken the development of methanol-fueled leaf blowers as an alternative. However, no manufacturer has yet certified a methanol blower, nor has any manufacturer indicated plans to do so in the near future, thus methanol-fueled leaf blowers operate in violation of California and federal law. If methanol engines were to be offered, they would need to comply with the same emissions standards as gasoline engines. The use of methanol also raises some concerns beyond those associated with a gasoline-fueled internal combustion engine. These include flame luminosity, as methanol burns with a pale flame, leading to safety issues, and toxicity.

7.4 Electric Equipment

Another technology in current use, particularly for residential applications, is powering the leaf blower with electricity. Electric equipment tends to be less expensive than the equivalent gasoline-powered equipment, with comparable performance on residential products. Staff investigated the products available at several mass market stores, and found that corded electric blowers are available. Additionally, AeroVironment, working under the auspices of the Los Angeles Department of Water and Power, has developed a prototype battery-powered blower for commercial use. As many as 1500 pre-production models will be distributed to various gardeners and landscapers to verify its utility for commercial use (L. Johnson, LADWP, pers. com.).

7.5 Alternatives to Leaf Blowers

Questions have been asked about the impacts of other methods of street cleaning, such as using a broom or washing down the street with water. No data could be located to permit an estimation of fugitive dust emissions due to using broom. An assessment of the amount of water that would be used in lieu of leaf blowers falls outside of the scope of work for this report. Data on whether or not these alternatives are louder or quieter than leaf blowers seem contradictory and many require an expanded study to verify.

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